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A Synopic Evaluation of Water Quality for Little Yellow Creek in Cumberland Gap National Historic Park

Matthew Thomas Johnson
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Matthew Thomas Johnson entitled "A Synopic Evaluation of Water Quality for Little Yellow Creek in Cumberland Gap National Historic Park." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

Randall W. Gentry, Major Professor

We have read this thesis and recommend its acceptance:

R. Bruce Robinson, John S. Schwartz

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A Synoptic Evaluation of Water Quality for Little Yellow Creek in Cumberland Gap National Historic Park

**A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville**

Matthew Thomas Johnson
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Abstract

This purpose of this study was to evaluate the water quality monitoring program in use in Cumberland Gap National Historic Park. Over 10 years of historical water quality data was compiled into a Microsoft Access database.

Water quality parameters considered indicative of ecosystem or fish health were used to evaluate the program. All sample sites were analyzed by the watershed they corresponded to. The sample mean, normalized confidence interval width, and normalized variance were calculated in order to compare parameters at sites in corresponding watersheds. The percentages of values exceeding EPA and literature water quality standards were also calculated to evaluate the monitoring network.

Water quality parameters were compared, and a more frequent sampling interval was suggested for various parameters at different network sites. Furthermore, parameters with significant exceedances of water quality standards were also recommended for increased sampling. Cadmium exceeded standards at four sites, all on Little Yellow Creek. Chromium and copper both exceeded acceptable levels at two sites on Little Yellow Creek. Mercury exceeded criteria at site YC1. Dissolved oxygen was recorded at low levels a significant number of times at YC5. Levels of pH did not meet standards at five sites from the entire network. Alkalinity did not meet water quality criteria at twelve of the sites.

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Chapter 1

Introduction

1.1 Cumberland Gap National Park

1.1.1 General

Cumberland Gap National Historic Park (the Park) covers over 20,000 acres where Virginia, Kentucky, and Tennessee coalesce (***Figure 1***). In the southern portion of the park, Little Yellow Creek flows through until its confluence with Davis Branch. Southwest of the park is the Fern Lake reservoir, which forms the headwaters of the part of Little Yellow Creek which passes through the Park. Currently, the National Park Service is in the process of obtaining the land containing these water bodies. Fern Lake is the source of water for the adjacent city of Middlesboro, Kentucky. According to recent trends, Middlesboro does not appear to be growing, and therefore, at present, Fern Lake is an adequate supply of water for the community. Fern Lake has a dam controlling its discharge, however, the only means used to regulate this discharge is the emergency spillway.

The park service is interested in evaluating flow in Little Yellow Creek and its water quality characteristics. They are especially concerned with the effect of the water quality on the fish in the creek and the ideal range of streamflow the creek required to support the fauna therein.

1.1.2 Data

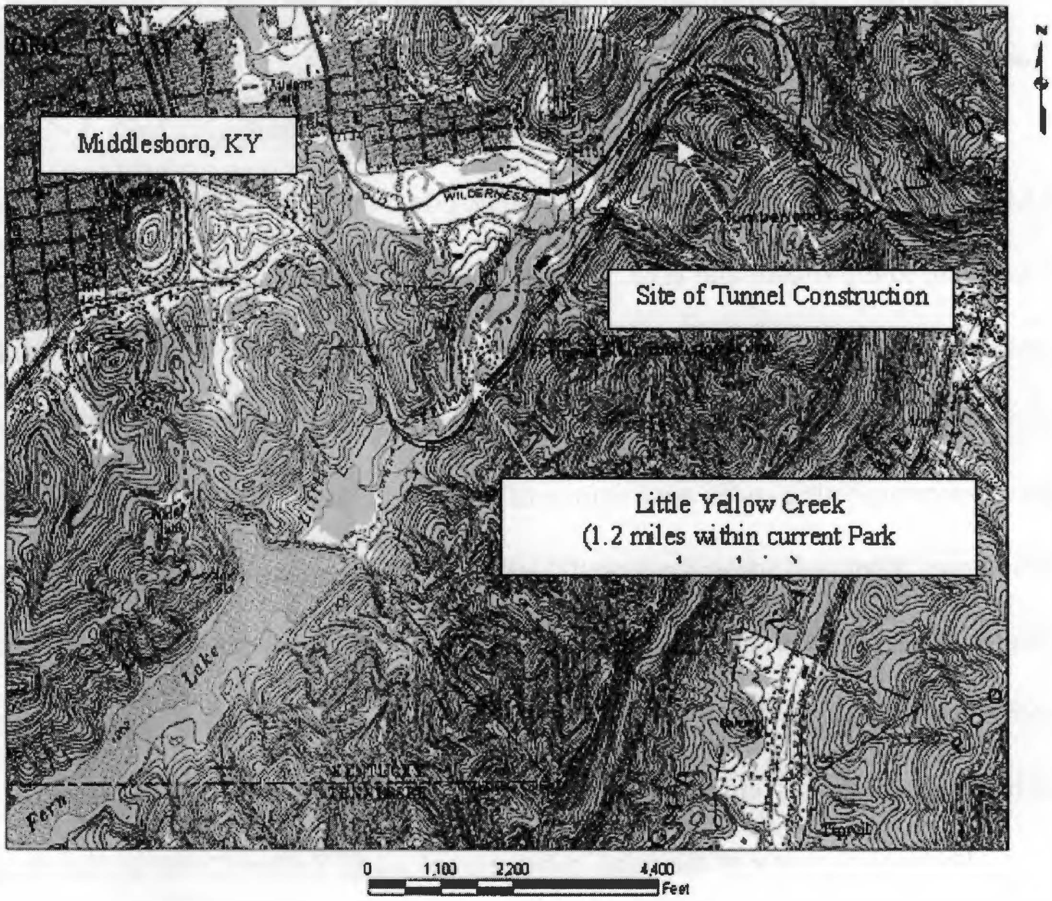
The Park has approximately ten years of water quality data for four different locations on Little Yellow Creek. The data consist of grab samples for suspended sediment and water at the four locations and rain samples for the park. The water quality monitoring began in the Park due to the construction of the Cumberland Gap tunnel. A map of the park area and location of the tunnel is shown in ***Figure 1***.

Water quality in the park is likely influenced by several different factors. In addition to the water chemical characteristics of Fern Lake, there are several tributaries flowing into Little Yellow Creek contributing to its chemical characteristics. There are many known abandoned mines located in the watershed possibly impacting the creek's water quality. Land use and its impact on water quality is not a significant factor in the park but could be more important in the area providing drainage to Fern Lake.

1.2 Fern Lake

1.2.1 General

In order to ensure an adequate water supply for the town of Middlesboro, Kentucky, the American Association, which owned coal properties surrounding Middlesboro, built the dam on Little Yellow Creek (Liddle, 1995). The dam was built of stone on a solid rock ledge with 8,000 cubic yards of masonry core. It was the first masonry damn built in the United States (Liddle, 1995). The dam itself is 660 feet long, 35 feet high, and 16 feet in width at the base. It produced a lake (Fern Lake) measuring 1.75 miles long with an estimated capacity of 400 million gallons. In a 1994 lake survey, the lake depth was estimated to be 35 feet (Liddle, 1995). The Fern Lake watershed is 4,544 acres. It is 125 to 1055 feet in width, 900 feet long, and has a max fetch of 1.2 miles. Aqua KWS, Inc. currently operates water intakes and the water treatment plant supplying Middlesboro (Liddle, 1995). The plant processes about 1.5 million gallons per day. Fern Lake capturees about 18.6 inches of runoff per year (Liddle, 1995).



Source: USGS 7.5 minute DRG topographic maps.

Figure 1. Site Location Map Showing Fern Lake and Little Yellow Creek

1.2.2 Water Quality Influences

Several influences on Fern Lake and Little Yellow Creek have been documented by Liddle (1995). The road from Tackett Creek down the Fern Lake watershed is a source of sediment to the stream and lake. Despite the disturbances caused by coal mining, the area along Fern Lake is well vegetated and appears stable (Liddle, 1995). Coal drill holes may be a source of groundwater contamination between aquifers (Liddle, 1995). Numerous prospecting roads are a source of erosion and sediment to the watershed. A 1994 survey displayed some areas on the lake that showed gullying and sloughing of hillsides due to wave erosion. However, these processes did not appear to be significant contributors to sedimentation (Liddle, 1995). Natural iron laden water and acidic water can be found at springs and seeps along the valley bottom.

The surface water in the south tributaries of Little Yellow Creek is slightly acidic with almost no mineral content. These streams show some signs of acid rain effects (Liddle, 1995). The tributaries from the north end of the watershed are more mineralized, alkaline, and tend to neutralize the slight acidity of the south side tributaries. Of the 43 tributaries in the watershed, 18 tributaries have been affected somewhat by past coal mining activities (Liddle, 1995). All of these tributaries are on the north side of Little Yellow Creek or adjacent to Fern Lake. These waters are more alkaline, higher in dissolved solids, sulfates, and other minerals, metals, and trace elements. Past mining improved water quality in the creek and lake by adding alkalinity and nutrients, while lowering acidity and corrosiveness of natural waters from sources other than the mines according to Liddle (1995). The mining in the watershed has allowed more groundwater storage, which supplies the stream during low flow (Liddle, 1995).

1.2.3 Areal Geology

The southern half of the watershed has been uplifted over geologic time to produce strata that are highly fractured, tilted up at angles of 45 to 50 degrees, and old in comparison to rest of watershed (Liddle, 1995). The Lee formation of the southern end of the watershed contains course-grained sandstones. The northern half of the watershed has consistent, horizontal, less fractured strata. The Brethitt formation, in this half of the watershed, has fine grain sandstones as thick as 100 feet. Faulting of the formation means fractures extend much deeper than on the northern side, producing more groundwater. The difference in groundwater quality of the two formations in the Fern Lake watershed results in higher sensitivity of Little Yellow Creek and Fern Lake to development or disruption of water supplies (Liddle, 1995).

1.3 Water Quality

1.3.1 General

Water quality is an essential aspect of virtually all environmental assessments. Measuring water quality over time is important in determining the source of harmful chemical characteristics and determining their possible impacts. Some chemical characteristics can be detrimental to wildlife, human consumption, and recreation at certain levels. Therefore, it is vital to have an adequate monitoring network in place to observe possible trends and detect these harmful levels. In turn, a connection between water quality characteristics and streamflow can be significant from a modeling perspective. With an extensive water quality history and knowledge of the watershed characteristics, the water quality can be approximately predicted via the quantity of streamflow, given a well understood correlation. Modeling water quality with streamflows can allow a manager to make rough predictions for certain water quality parameters.

1.3.2 Importance to Fish

Fish are among the most susceptible to harmful water quality characteristics. For instance, pH levels below 6.5 and above 9 are lethal for fish populations (Alabaster and Lloyd, 1980). Tolerable ranges for temperature and dissolved oxygen are also critical for fish survival. Some dissolved ions and pollutants can be harmful in high concentrations. Viable fish populations are extremely important in maintaining biodiversity and ecosystems. They are also important for human consumption and recreational aspects. Furthermore, the National Park Service is especially interested in preserving native fish populations in their protected reaches as one of their mission goals.

1.4 Objectives

The following objectives of this study are focused on assisting the park officials in evaluating water quality in Little Yellow Creek and their existing water quality monitoring program:

1) Evaluation of the current sampling network and determination of a more optimal sampling frequency
2) Determination of most probable sources of abnormal values in water quality constituents
3) Evaluation of current water quality and streamflow conditions in the creek

Chapter 2

Literature Review

2.1 Fish Stream Condition Criteria

Some water quality parameters, important as indicators of river ecosystem health, are discharge and the input of nutrients (nitrogen and phosphorus) to a stream (Lorenz et al., 1997). Other parameters significant for fish health were listed and described in detail by Alabaster and Lloyd (1982). The indicator parameters used in this study are pH, turbidity, alkalinity, streamflow, dissolved oxygen, total suspended solids, temperature, nitrogen, and phosphorus.

Assessment of water quality exceedances is important to determine if the water body is experiencing natural variation or significant influences from other sources. The probability of a water quality standard exceedance at a given point can be assessed by the percentage of samples exceeding the standard (EPA, 1997). The water quality criteria for aquatic life used in this study was adapted from EPA guidelines. These parameters and ranges are summarized in ***Table 1*** (EPA, 2002). The parameters and criteria presented in ***Table 1*** were used to determine the standard exceedances. However, only the indicator parameters listed above were used in the other aspects of this study.

The pH range not directly lethal to fish is 6.5 to 9 (EPA, 2002). However, toxicity of several common pollutants is affected by pH changes in this range, causing lethal effects. For a pH below 5, fish deaths may be expected, though some species may be acclimated to as low as 3.7. Values of pH between 9 and 10 may be harmful to some species and above 10 lethal to all others (Alabaster and Lloyd, 1982). Acclimation of

Table 1. Water Quality Standards for Aquatic Life from EPA (2002)

	EPA (mg/L)	
	CMC*	CCC**
Arsenic	0.34	0.15
Cadmium	0.002	0.00025
Chromium	0.016	0.011
Copper	0.013	0.009
Lead	0.065	0.0025
Mercury	0.0014	0.00077
Nickel	0.47	0.052
Selenium	0.02	0.005
Silver	0.0032	
Zinc	0.12	0.12
Cyanide	0.022	0.0052
Aluminum	0.75	0.087
Chloride	860	230
Iron		1
DO		<5
pH (pH units)		6.5-9
Temperature (ºC)		0
Alkalinity		20

*CMC = Criterion Maximum Concentration
**CCC = Criterion Continuous Concentration

fish to low pH levels did not increase survival rates when exposed to lethal pH levels in lab studies (Alabaster and Lloyd, 1982).

There is abundant evidence acclimation to low dissolved oxygen levels can occur. However, sudden exposure to a moderately high concentration of carbon dioxide causes normally tolerable low dissolved oxygen to become rapidly fatal. A minimum of 5 mg/L of dissolved oxygen is a satisfactory limit for most processes required for a successful fish life cycle (Alabaster and Lloyd, 1982).

Alkalinity is important to fish and aquatic life because of its measurement of the buffering capacity of water. A higher concentration of alkalinity represents a water's ability to buffer pH changes (EPA, 1986). The minimum concentration criteria for alkalinity is 20 mg/L as $CaCO_3$ (EPA, 2002).

Concentrations equal to and greater than 0.013 mg/L of copper are lethal to fish. The difference in the range is attributed to different water hardness values, species of fish, duration of exposure, and stage in life cycle (Alabaster and Lloyd, 1982).

The normal range of temperature for which fish are adapted is 0 to 30°C. Low levels of dissolved oxygen have been shown to reduce lethal high temperatures for some species of fish. Different temperature conditions are required at different times of year to meet needs for different life stages of fish (Alabaster and Lloyd, 1982). Lab studies have used thermal gradients in tanks to demonstrate fish species select certain temperature ranges. These studies have been verified by field observations of similar fish behaviors (Coutant, 1987).

Minimum flow criteria are also important for maintaining fish populations and ecosystems. Minimum instream flows are generally determined by three different categories which include historic flow regime, hydraulic, and habitat methods (Orth and White, 1993). Historic flow methods depend on the measured or estimated flow regime of a stream (Jowett, 1997). Of these methods, the Tennant (1976) method is the most widely used. This method assumes a certain percentage of the mean flow is required to maintain a healthy stream ecosystem. Tennant considered 10% of the mean flows to be the lower limit for aquatic life. Furthermore, he stated 30% of the mean flows provide good to optimum conditions for aquatic life-forms.

Hydraulic methods of determining minimum flows relate parameters of hydraulic geometry of stream channels (determined by cross-section surveys) to discharge (Jowett, 1997). Variation in wetted perimeter with discharge is the most commonly used hydraulic method. These variations in wetted perimeter and other hydraulic parameters can be calculated by measuring different flows (Mosley, 1982). The two criteria used with this method are the point of inflection when wetted perimeter is graphed versus flow and percentage habitat retention, a percentage of the wetted perimeter is retained at mean flow (Jowett, 1997).

Habitat methods are based on hydraulic conditions that meet biological requirements instead of the hydraulic parameters themselves (Jowett, 1997). These methods are considered more accurate (Annear and Conder, 1984) and more flexible than other methods. They compare predicted water depth and velocity with habitat suitability criteria to determine the required habitat for an indicator aquatic species (Leopold and Orth, 1988; Aadland, 1993). Indicator species are used in habitat methods because varying flow for the habitat of one species can conflict with the habitat of another species. Of the available methods, the physical habitat simulation component (Milhous et al.,

1984) of the instream flow incremental methodology (IFIM) is the most widely used. IFIM is a tool that assists in evaluating different water management alternatives while considering the consequences on habitat (Bovee et al., 1998). Habitat variability can be modeled spatially and temporally using the IFIM method (Bovee et al., 1998). Habitat methods require good knowledge of the stream ecosystem and some clear management objectives to resolve habitat conflicts (Jowett, 1997). Furthermore, they necessitate cross-section surveys and habitat suitability criteria. Habitat methods can be adjusted to consider seasonal variation in flows and flood frequency (Jowett, 1997).

2.2 Dam Effects

Studies have shown that virtually all major chemical components of river water are derived principally from diffuse catchment processes and not direct effluent discharges (Edwards, 1995). Measurements of various water quality constituents at a monitoring station in a watershed represent the cumulative effects of all sources of pollutants and natural solutes upstream from the station. These measurements do not respond instantaneously to the changes in land uses, climate, sources of pollutants, and other influences of the watershed. (Zou and Yu, 1996)

Freshwater ecosystems have evolved to the rhythms of natural hydrologic variability, periodic and episodic water flow patterns. An evaluation of the characteristics required for healthy functioning can begin with a description of the natural or historical flow patterns for streams, rivers, wetlands, and lakes (Baron et al., 2003). Damming rivers and dampening natural variations in flow rates by maintaining minimum flows year round have contributed to widespread loss of native fish species (Baron et al., 2003). The invertebrates, algae, vascular plants, and bacteria in freshwater systems are highly adapted to the specific sediment and organic matter conditions of their environment, as are many fish species, and do not persist if changes in the type, size, or frequency of sediment inputs occur. Dams alter sediment flows both for the reservoirs behind them and the streams below, silting up the former while starving the latter. This sediment capture in turn cuts off normal sand, silt, and gravel supplies to downstream reaches, causing streambed erosion that both degrades in-channel habitat and isolates floodplain and riparian wetlands from the channel during rejuvenating high flows (Baron et al., 2003).

Water temperature directly regulates oxygen concentrations, the metabolic rate of aquatic organisms, and associated life processes (Baron et al., 2003). Water temperature can change dramatically downstream of dams (Baron et al., 2003). Water discharged from reservoirs is roughly equivalent to natural stream conditions or a little warmer from January through March. By April, discharge is still under the influence of main body of stored water in the reservoir and remains colder than natural storm temperatures (Pfitzer, 1954). Tailwater temperatures will remain colder than natural stream temperatures as long as the supply of winter-stored water is available. From the start of October until January, tailwater temperatures are warmer than natural stream temperatures since the main body of the reservoir cools much more slowly than the inflowing streams. The annual temperature pattern is characterized by the relationship between the volume of winter-stored water in the reservoir and the volume of water discharged from April to October. As cold winter-stored water is discharged, it is replaced by warm inflowing water (Pfitzer, 1954).

Low dissolved oxygen occurs in the fall when warmer temperatures are discharged and when biochemical oxygen demand (BOD) in the reservoir reduces the available supply of oxygen. This is rapidly replenished during the fall vertical circulation in the reservoir (Pfitzer, 1954).

Excessive levels of turbidity are encountered when lateral inflows from tributary streams carry large volumes of turbid water. Noticeably turbid discharges usually occur in the winter (Pfitzer, 1954).

Typically for the Tennessee region, the pH of tailwaters is around 7 (Pfitzer, 1954). The lowest pH occurs with the highest water temperatures. Also typical for the area, free carbon dioxide is less than 2 parts per million (ppm) in all tailwaters most of the time (Pfizter, 1954). If no-flow periods occur during the warm months for extended periods of time (36-48 hours), water begins to warm to undesirable temperatures. Also, no-flow periods expose areas of stream bottom, which reduces or eliminates productivity (Pfitzer, 1954).

One management technique to restore these systems to a more natural and sustainable state is restoring some of the natural variations in stream flow (Baron et al., 2003). Most systems are inherently resilient to a particular pattern of disturbance, and their plant and animal communities will persist as long as conditions fluctuate within a certain range of streamflows. Once a threshold is reached, however, these ecosystems may change rapidly to a new stable state that is very difficult to reverse. Detecting such trends before problems become critical requires both monitoring the biological and physical conditions in freshwater ecosystems and understanding the natural ecological dynamics of the system. The sustainability of aquatic ecosystems can best be ensured by maintaining naturally variable flows, adequate sediment and organic matter inputs, natural fluctuations in heat and light, clean water, and a naturally diverse plant and animal community (Baron et al., 2003). Aquatic communities are not simply isolated bodies or conduits but are tightly connected to terrestrial environments (Baron, et al., 2003).

2.3 Sampling Frequency

2.3.1 General

Statistics has a major role in three areas in the assessment of water quality samples: determining the characteristics of background water quality, detecting changes in water quality (departure from background conditions, including trends or exceedances of standards), and quality control. There are three categories of general objectives for regulatory water quality management (Ward et al., 1986).

1) Determining the means in water quality parameters that can be used to describe water quality in a spatial context
2) Detecting trends in quality that can be used to describe water quality over time
3) Detecting exceedances of stream standards or determining the probability of exceedance

A large portion of the costs of operating a monitoring network is directly related to the frequency of sampling. Also, the reliability and use of water quality data derived from monitoring networks are similarly related to the frequency of sampling (Sanders et al., 1978). Since individuals sampling for water quality will differ in their expertise in sampling, the sampling used to obtain similar data and the estimation of ambient water quality characteristics will differ depending on the individual. In a series of random events the accuracy of the estimate of the mean is a function of the number of sample observations (Sanders et al., 1978).

All of the samples used in this study were grab samples. Though grab samples do not provide some benefits gained by use of constant monitoring, they do have some beneficial aspects. Grab samples can be used when it is desired to (WMO, 1998):

1) characterize water quality at particular times and locations
2) provide information about approximate minimums and maximums
3) allow collection of variable volumes of samples
4) analyze data for parameters which are likely to change
5) apply to stream which flow intermittently
6) evaluate history of water quality based on relatively short sampling intervals

2.3.2 Outliers

Before the data can be analyzed, some statistical elements of the data must be accounted for. Boxplots are often used as a simple method of displaying a set of data. The plot displays several aspects of the data including the outliers. The outliers are the points on the boxplot outside the lower and upper inner and outer fences, which are defined using the interquartile range. Outliers located between the inner and outer fences are considered mild outliers, and outliers beyond the outer fence are considered extreme ouliers. The inner and outer fences are calculated by (Ott and Longnecker, 2001):

lower inner fence: $Q_1 - 1.5(IQR)$
upper inner fence: $Q_3 + 1.5(IQR)$
lower outer fence: $Q_1 - 1.5(IQR)$
upper outer fence: $Q_3 + 1.5(IQR)$

where: Q_1 = point where 25% of the data is below that point or the lower quartile
Q_3 = point where 75% of the data is below that point or the upper quartile
IQR is the interquartile range or the distance between the lower and upper quartiles

Boxplots are appropriate for summarizing data because they display the data without the influence of outliers and simultaneously isolate the outliers as points of particular significance (Hoaglin et al, 1983).

Another more powerful method of determining outliers using multivariate methods is using the Mahalanobis distance. Transformed by a covariate matrix, the Mahalanobis distance is the Euclidean distance of an observation from the multivariate mean of a set of data. In other words, while taking into consideration correlation between parameters, the Mahalanobis distance is the distance of a data point from the centroid of the multivariate data set (Manalanobis, 1936).

$$D^2 = (x-m)^T C^{-1}(x-m)$$

where: D^2 = Mahalanobis distance
x = vector of data
m = vector of mean values of independent variables
C^{-1} = inverse covariance matrix of independent variables
T = indicates vector should be transposed

While using these outlier identification methods, unusual looking outliers should not be removed simply because they do not the fit the data set (Helsel and Hirsch, 2002).

2.3.3 Statistical Assumptions

Three assumptions of importance when performing statistics in water quality are independence of observations, homogeneity of variance, and normality. In general, water quality violates most of the above assumptions (Smith et al., 1982). Independence of samples assumes when selecting a sample of observations, every possible combination of observations has an equal chance of being chosen (Ponce, 1980). However, routine regulatory water quality monitoring is systematic sampling, sampling starting at a random point and continuation of sampling at a given interval of time. Systematic sampling presents problems when drawing cause-effect conclusions from statistical analyses. A single event can cause cyclic patterns or correlation between samples in a set of data (Ward et al., 1986).

2.3.4 Time Series

There are several factors that cause water quality to change on a temporal scale: random changes caused by random environmental factors or events, seasonal changes, and serial correlation. The results of removing seasonal effects are less 'variance' in the data. In water quality populations, the degree of correlation generally increases as samples are taken closer together in time. In evaluating data, the simplest and most widely used method is to consider neither the effects of seasonal variation nor serial correlation. Another method is to consider the effects of seasonal variation only. The most accurate method is to consider the effects of both seasonal variation and serial correlation (Loftis and Ward, 1980).

Time series plots of raw water quality data provide a good overview of the water quality temporal patterns. A general view of the seasonality and trends can be inferred from these plots. Some tests for normality include the Chi-Square goodness of-fit test, the Shapiro-Wilk, and the Kolmogorov-Smirnov test. If the data is not normally distributed, a decision must be made as to whether the degree of nonnormality invalidates data analysis procedures. If the normality assumption cannot be used, nonparametric tests and data transformations can be used. The time series plot gives an indication whether there have been dramatic changes in variance. If changes are detected, the record can be divided. When variances are heterogeneous to the extent to cause problems, it may be necessary to study the data record for the potential cause of the changes (Ward and Loftis, 1986).

In the method where seasonal variation and serial correlation are ignored, the variance of the sample mean is computed by (Loftis and Ward, 1980):

$$\mathrm{var}(X) = \sigma^2/n$$

where: var (X) = variance of the sample mean
σ^2 = variance of the water quality variable
n = number of samples

Seasonal variation in water quality indicates a water quality variable can be approximately predicted for a time of year. Seasonal variation can be described by a deterministic function and then removed from the data. An example of seasonal variation would be the rise and fall of temperatures according to the time of year. Serial correlation is the tendency of an observation to be similar to observations made previously. When considering the natural variability of a parameter, a group of observations that are serially correlated will contain less information than would a group of n uncorrelated observations (Loftis and Ward, 1980). When serial correlation is considered, the variance of the sample mean is computed from (Loftis and Ward, 1980):

$$\mathrm{var}(X) = \sigma^2/n^2 \left[n + 2 \sum_{k=1}^{n} (n-k)p(k)\right]$$

where: var (X) = variance of the sample mean
n = number of samples per year
p(k) = lag – k autocorrelation coefficient
σ^2 = variance of water quality variable with seasonal component removed

Computing the variance of the sample mean, which accounts for both seasonal variation and serial correlation, requires a rather extensive data record. The variance of the network sample mean is computed by (Loftis and Ward, 1980):

$$\mathrm{var}(X) = 1/m^2[\Sigma \mathrm{var}(X_i)]$$

where: X_i = sample mean at station i
m = number of stations
X = sample mean of the individual station sample means (network sample mean)

Among the other methods available to deal with seasonality and serial correlation are linear multivariate methods. These methods are commonly applied to multivariate sets of physical and chemical data for reducing them to manageable subsets (Champely et al., 1997). When considering the frequency properties of time series, the Fourier method is more suitable for separating a long-term trend from periodic variations. However, this technique becomes less powerful if samples are not collected regularly. The Box-Jenkins methodology aims to describe "stationarity" after removing trends and periodicity (Champely et al., 1997). In other words, it enables a description of the time-independent autocorrelation structure relying only on the time lag between two sampling dates. Furthermore, this method requires a time series measured at equal intervals of time (Champely et al., 1997).

2.3.5 Trends

There are three approaches to detecting trends such as seasonality in water quality data including graphical display, parametric tests, and non-parametric tests. Time plots can supply information on trends, extreme values, known and unknown interventions, dependencies between observations, and long-term cycles. Parametric tests are based on the assumption that the data is normally distributed. These tests should only be used if this assumption is valid or a transformation of the data can be performed to satisfy the assumptions. The t-test is used as a robust parametric test because it performs well for small data sets or if the normality assumption is violated. From the t-test, the data can be divided for comparison purposes, and linear regression can be used to assess trends within those time periods. However, it does not perform well if the data is highly skewed. Typically, water quality data are skewed. Linear regression can be used to assess trends within given time periods. The slope of a line can describe the significance of a linear trend. Some nonparametric tests used in previous studies include the Wilcoxon test, a seasonal Kendal Tau test, the Mann-Whitney test, and the Spearman Rho test (Ward and Loftis, 1986). In general, nonparametric methods appear better suited to water quality data time series than parametric methods (Thas et al., 1998).

There are several ways to determine correlation between points in a data set. Two of these methods are the Pearson Product Moment and Spearman's Rho. Pearson's Product Moment or referred to as the correlation coefficient, r_{xy}, is defined by (Ott and Longnecker, 2001):

$$r_{xy} = s_{xy}/(s_x\, s_y)$$

where: s_{xy} = the standard deviation of both x and y values
s_y = the standard deviation of the y values
s_x = the standard deviation of the x values

Spearman's Rho uses measures of monotonic relationships and is Pearson's Product Moment Correlation Coefficient of the Ranks. For the ranks of x (Rx_i) and ranks of y (Ry_i), rho can be computed from the equation:

$$\text{rho} = \sum_{i=1}^{n} \frac{(Rx_i\, Ry_i) - n((n+1)/2)^2}{n(n^2 - 1)/12}$$

where: $(n+1)/2$ = the mean rank of both x and y.
n = number of data pairs

Yet another method used in considering the seasonality of water quality data is the seasonal Mann-Kendall test developed by Hirsch et al. (1982). The test uses a Mann-Kendall statistic S_k for each season k:

$$S_k = \sum_{i=1}^{n_k-1} \sum_{j=i+1}^{n_k} \operatorname{sgn}(Y_{jk} - Y_{ik})$$

where: Y_{jk} and Y_{ik} = observations from season k in year j and i, respectively
n_k = the number of years including season k

These statistics are summed over the p different seasons to form the overall test statistic S_n:

$$S_n = \sum_{k=1}^{p} S_k$$

where: S_k = Mann-Kendall test statistic

Hirsch et al. (1982) apply a continuity correction on the overall test statistic S_n:

$$Z_n = \begin{cases} \dfrac{S_n - 1}{(\mathrm{Var}(S_n))^{1/2}} & \text{if } S_n > 0 \\ 0 & \text{if } S_n = 0 \\ \dfrac{S_n + 1}{(\mathrm{Var}(S_n))^{1/2}} & \text{if } S_n > 0 \end{cases}$$

where: S_n = the overall test statistic

This test is useful because it is usable even when there are missing data, correlated data, or values recorded at detection limits (Antelo et al., 1998). Therefore, it is extremely useful as a water quality data application.

In order to quantify the trend components in time series, the slope of the trend is multiplied by the time differential from the origin of the trend (Sanders et al., 1978). The seasonal Mann-Kendall trend slope estimator is calculated as follows (Hirsch et al., 1982):

$D_{ij} = [(Y_i - Y_j)/(X_j - X_i)]$ for $i<j$

where: Y is the variable of interest

X is the time at which the i^{th} observation was taken

2.3.6 Measures of Central Tendency

In water quality monitoring, an important quantity is the mean value. The use of confidence limits around the mean as a way to guide the selection of the number of samples to be taken in a given time period has been discussed by several authors (Ward and Loftis, 1986, Ponce, 1980, Schaeffer and Janardan, 1979, Dunnette, 1979, Sanders and Adrian, 1978). It has been assumed in a previous study confidence interval widths can be compared within a water quality network (Loftis and Ward, 1980). By comparing these widths, the corresponding sampling intervals can be compared. Increasing the sampling interval for a particular site or parameter with a relatively large confidence interval width can decrease the width to a value similar to the other widths in the network. As a result, the characteristic variability of a watershed or system is captured by all sites in the monitoring network. If a random variable is not normally distributed, practical implications of the Central Limit Theorem provide for continual use (Ward et al., 1979). The Central Limit Theorem states that the distribution of an average tends to be normal, even when the distribution from which the average is computed is non-normal. The confidence interval width about the mean for a set of data is:

$R = 2\sigma_x t_{(\alpha/2,N-1)}/N^{1/2}$

where: σ_x = mean of the set of data
N = number of points in the data set
$t_{(\alpha/2,N-1)}$ = the upper critical value of the t-distribution with N-1 degrees of freedom
x = random variable

As the range about the sample mean decreases, precision of estimates increase (Ward et al., 1979). Measures of central tendency for a given time period can be expressed as a mean, median or mode. In order to account for uncertainty in sample measurements, these measures of central tendency can be reported as a confidence interval (Ward and Loftis, 1986).

In a study done by Ward and Loftis (1980), certain sampling intervals were affected by different statistical characteristics. Using sampling intervals of 1 day to approximately 12 days, the effect of serial correlation was very important. When using sampling intervals of approximately 12 days to approximately 34 days, serial correlation and seasonal variation tended to cancel each other out. Using a sampling interval larger than 34 days, the effect of seasonal variation alone was important to consider. Sampling at higher frequencies may be used to increase the level of information but may require that more sophisticated statistical tools be used in the data analysis. If higher sampling frequencies are introduced without a change in data analysis procedures, considerable error may be introduced (Loftis and Ward, 1980). The need for data to be collected consistently at a given location using consistent collection and measuring techniques on a regular schedule and over a substantial number of years has been stressed repeatedly (Ward et al., 1986).

Chapter 3

Methodology

3.1 General

The main objective of this study was to evaluate the current water quality monitoring program in place at the Park. This objective was to be met by use of graphical and numerical statistical methods. The data used in this study were obtained from the Park. The data were collected by personnel from Tennessee Technological University for the Park between 1990 and 2001. Between thirty and forty parameters were measured with each sample during this time. There is also limited data collected in 2002 and 2003 by park staff. Only pH, dissolved oxygen, turbidity, conductivity, and temperature were measured in the samples taken by the park staff during this time. Over thirty-two sites were monitored to some degree. Though other sites were monitored, fewer than five samples were collected at these points. Therefore any statistics derived from these sites was considered inconclusive. The thirty-two sites included in this study and the streams present in the Park are shown in ***Figure 2***, ***Figure 3***, and ***Figure 4***. All sites were sampled intermittently with only a few samples spaced evenly at most monthly or biweekly.

The data was compiled into a Microsoft Access database for the Park. From the compiled water quality database, dissolved oxygen, streamflow, pH, turbidity, total suspended solids, temperature, nitrogen, phosphorus, and alkalinity were selected as indicator parameters of fish and ecology health (Alabaster et al. 1982, Lorenz et al. 1997).

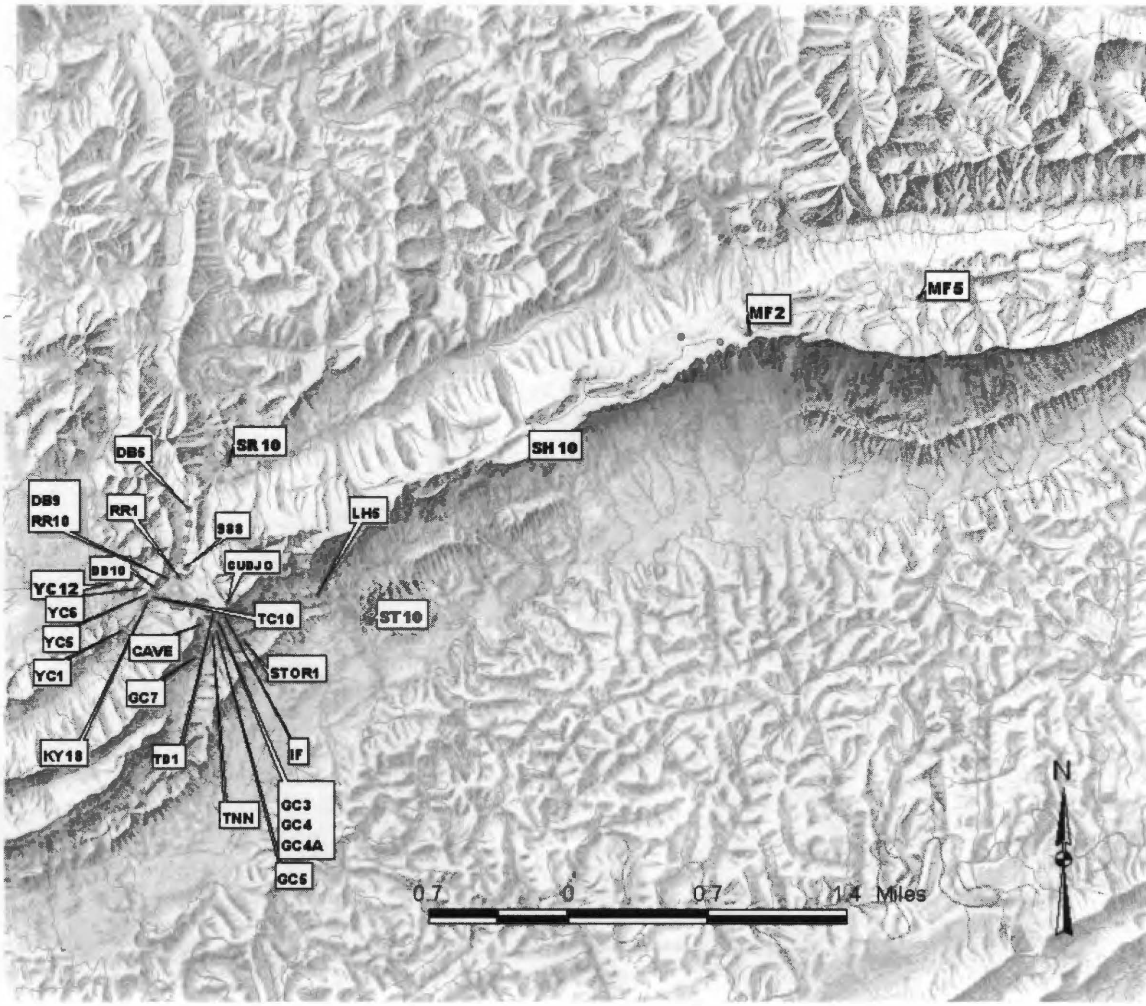


Figure 2. **Sampling Locations**

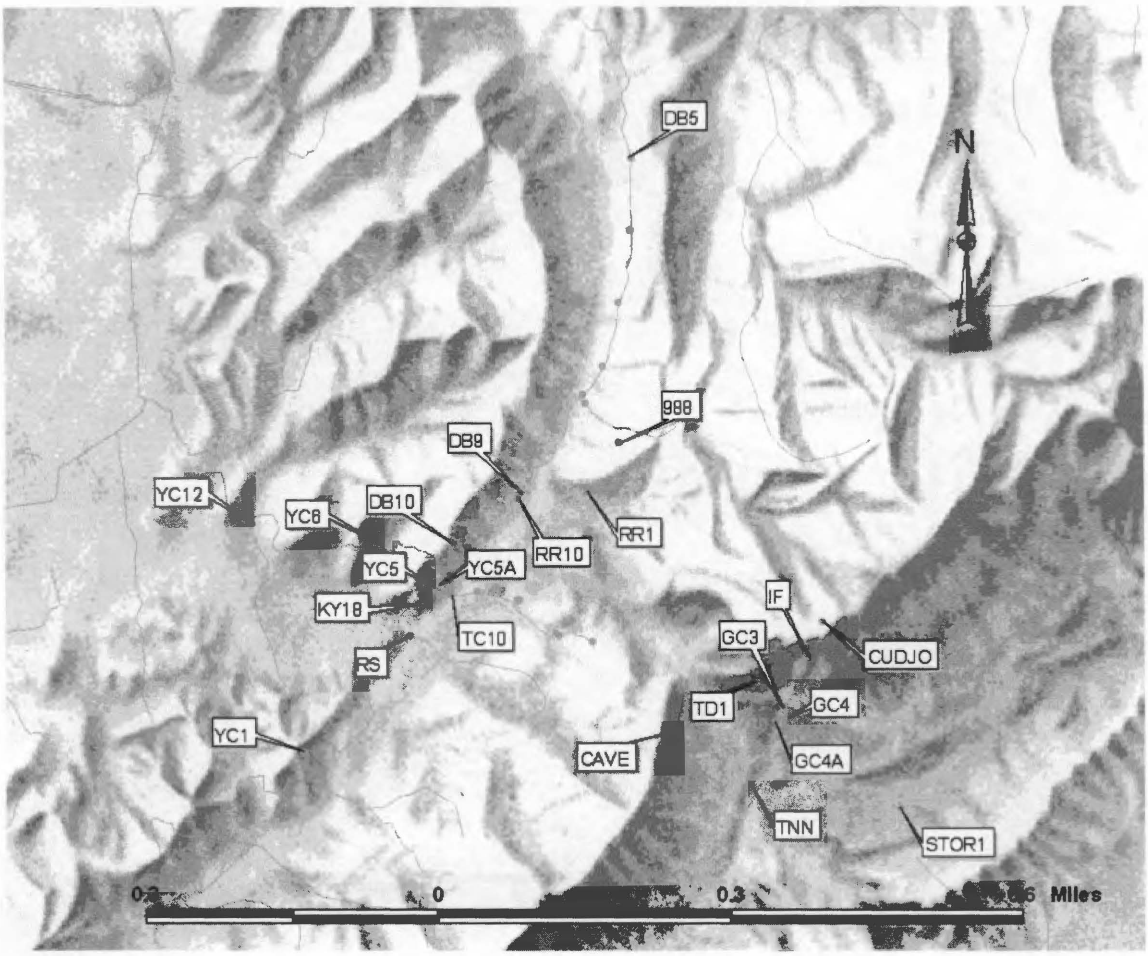


Figure 3. Sampling Locations in Southern Portion of Cumberland Gap National Park

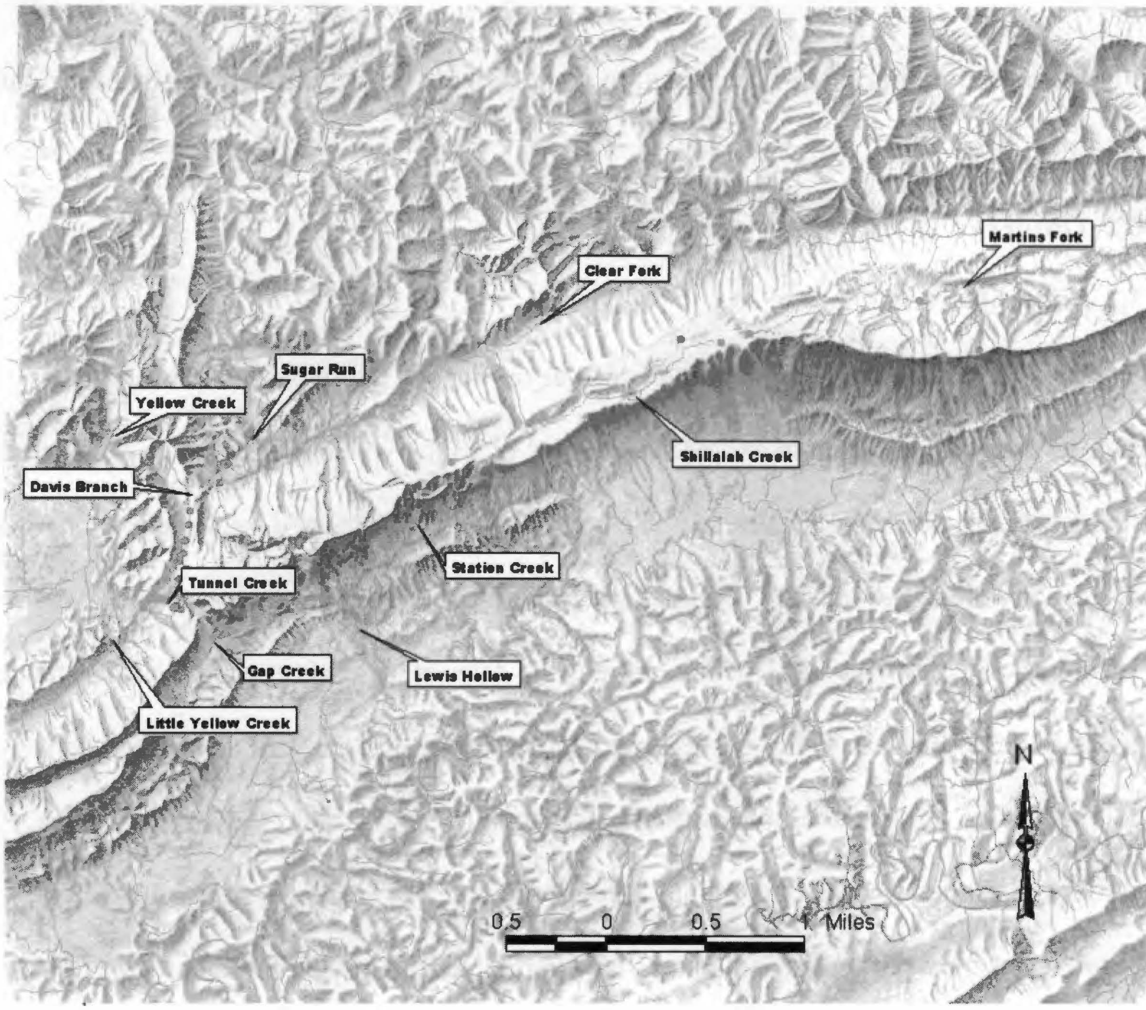


Figure 4. Streams in Cumberland Gap National Park

and were used in this study for evaluation. An example of the form used to enter the data is in ***Figure 5***.

3.2 Outliers

3.2.1 Boxplots

The first step in analyzing the data was to identify likely outliers present in the data set and decide which to exclude. Boxplots of all the water quality parameters listed above for each site were generated. The boxplots were constructed by finding the median of the data, the upper quartile, and the lower quartile. The upper and lower quartiles form the edges of the box, and the median divides the data set. Values outside the inner fences are considered outliers. Mild outliers are denoted by an 'O', and extreme outliers are denoted by an '*'. The numbers which correspond to the 'O' and '*' symbols are the numbers assigned to each data point in the set of data. For instance, data point 128 is equal to 8.4 for a particular parameter. An example of the box plots is shown in ***Figure 6***.

3.2.2 Correlation

After identifying outliers from the box plots, a multivariate outlier identification technique was used to further narrow the number of outliers. Before this multivariate method could be used, the correlations between water quality parameters were calculated. Pearson's product moment correlation coefficients were generated for each site for every possible combination of water quality parameters. An example of the output file generated in SPSS of these coefficients is shown in ***Table 2***.

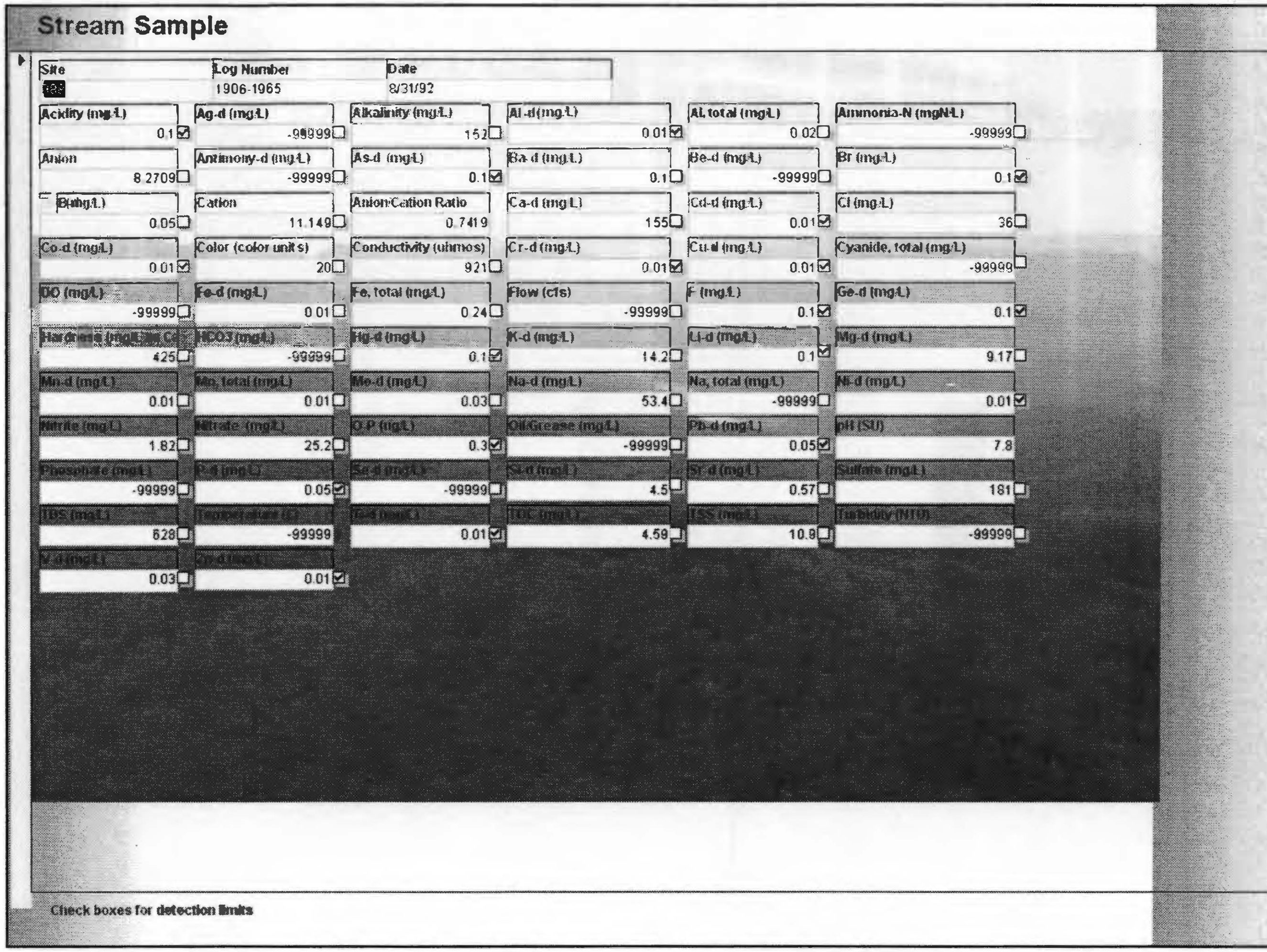


Figure 5. Data Entry Form

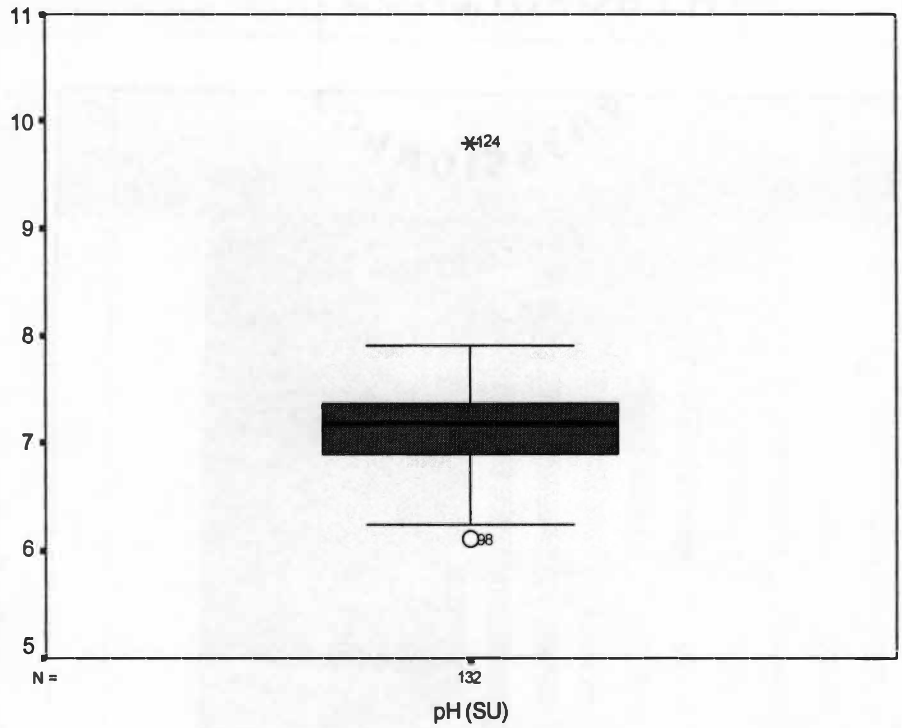


Figure 6. Box Plot Example

Table 2. SPSS Correlation Output Example

		Hardness (mg/L as CaCO3)	Alkalinity (mg/L)	Mg-d (mg/L)	Ca-d (mg/L)
Hardness (mg/L as CaCO3)	Pearson Correlation	1	.723**	.671**	.996**
	Sig. (2-tailed)	.	0.000	0.000	0.000
	N	101	101	101	101
Alkalinity (mg/L)	Pearson Correlation	0.723**	1	.825**	0.683
	Sig. (2-tailed)	0.000	.	0.000	0.000
	N	101	104	104	104
Mg-d (mg/L)	Pearson Correlation	.671**	.825**	1	0.609
	Sig. (2-tailed)	0.000	0.000	.	0.000
	N	101	104	104	104
Ca-d (mg/L)	Pearson Correlation	.996**	.683**	0.609	1
	Sig. (2-tailed)	0.000	0.000	0.000	
	N	101	104	104	104

** significant correlations

3.2.3 Multivariate Methods

Once the correlation between parameters was established, these correlated parameters were used in the multivariate outlier identification technique, which was comprised of calculating the Mahalanobis distances. Only correlations considered significant for the two-tailed test were used in the outlier identification. The Mahalanobis distances for the correlated parameters were calculated and compared. Data points with Mahalanobis distances significantly greater than other data points for a water quality parameter at a site were identified as outliers. For instance, the majority of the distances in most data sets were within a certain range which varied between data sets. The data points corresponding to distances outside this range were considered outliers.

Only outliers identified in both the multivariate method and the boxplots were excluded from the final dataset.

3.3 Data Analysis

3.3.1 Sample Mean

The mean of the corrected data was calculated along with its confidence interval and the width of the confidence interval. The confidence interval widths for several different sampling intervals were calculated and compared. All the confidence interval widths were normalized by dividing by the geometric mean of each variable similar to a previous study by Loftis and Ward (1980). After comparing confidence interval widths between different sites within each watershed, some parameters were suggested for more frequent sampling. This suggestion relies on the confidence interval widths and their corresponding sampling intervals. In order to drive a confidence interval width toward similar values as other sites in a network, more samples or more frequent sampling can be carried out for the parameter.

3.3.2 Data Exploration

Generally examining the database, the data was highly erratic temporally, and most sites' data contain years of missing data between sampling points. As a result, the analysis of the water quality time series at each site was severally limited. Though some statistical methods allow for missing points of data, analyses such as the seasonal Mann-Kendall test (Hirsch et al., 1982), do not allow for multiple years of missing data. Lengthy periods of time cannot be produced to fulfill statistical data procedures. Therefore, the procedure described above using the seasonal Mann-Kendall test could not be used to evaluate the current sampling frequency. Using the mean of the data at each site, a limited evaluation of the water quality parameters themselves was completed. The sampling sites were distributed according to the corresponding water body or watershed. A summary of this distribution is shown in ***Table 3.*** Each stream in the Park is affected by differing influences. As a result, sorting the sites in this manner allows the data generated from each site to be compared with water quality under similar impacts.

The sample mean, variance, confidence interval around the mean, and width of that confidence interval were calculated for every site. The confidence interval widths were normalized by dividing by the geometric mean of all the sites within a corresponding watershed. The geometric mean was used to normalize confidence interval widths in a previous study (Loftis, 1980). The variances were normalized by dividing by the highest value of the same group of sites after considering the outliers.

Table 3. Site Distribution

Stream	Sites
Martins Fork	MF2, MF5
Shillalah Creek	SH10
Sugar Run	CUDJO, SR10
Davis Branch	988, 988B, DB5, DB9, DB10, RR1, RR10
Little Yellow Creek	KY18, RS, YC1, YC5, YC5A, YC6, YC12
Tunnel Creek	TC10
Gap Creek	GC3, GC4, GC4A, GC5, GC7, IF, STOR1, Tunnel, Tunnel Cave
Station Creek	ST10
Lewis Hollow	LH5
Cleark Fork	CUDJO, SH10, SR10

Various methods have been used to normalize variances, but the extreme value was chosen for this study. All of the data and calculations are provided in ***Appendix A***.

3.3.3 Water Quality Standard Exceedances

Also considered in evaluating the current water quality monitoring was the exceedance of established water quality criteria from EPA for stream life (EPA 2002). The percentages of samples exceeding the standards listed in ***Table 1*** were calculated for the water quality parameters. Exceedance of water quality thresholds is considered significant when the percentage of samples exceeding is more than 10% (EPA, 1997). The significant values calculated are listed in ***Table 4***. A few sites had 100% exceedance, but these sites only had a few samples (less than 10). Though more samples would provide a better description of the state of the water quality, exceedances from a few samples can indicate a significant number of exceedances should be expected in future samples (EPA, 1997).

3.3.4 Streamflow Analysis

Using the data available and the Tennant method (1976), the minimum flow for 'short-term' survival of aquatic life (10% of the mean flow) is 0.66 cubic feet per second (cfs) for Little Yellow Creek. The flow that provides satisfactory protection of aquatic organisms (30% of the mean flow) is 1.98 cfs for Little Yellow Creek. These flows were calculated using the mean of the streamflow data and assuming most of these data points represent baseflow conditions in Little Yellow Creek. Outlier flows from the outlier analysis discussed previously were excluded because the mean flow would be skewed

Table 4. Significant Water Quality Exceedance Percentages

Water quality parameter	988	db5	db9	db10	ky18	lh5	mf2	mf5	rr1	rr10	rs	sh10	st10	yc1	yc5	yc5a	yc6	yc12
Cadmium														75.0%	20.0%	22.2%	25.0%	
Chromium														25.0%			20.0%	
Copper														25.0%			25.0%	
Mercury														20.0%				
DO															16.7%			
DO% Sat			24.3%	16.3%	16.7%							20.0%		31.3%				24.1%
ph							77.8%	100.0%		13.0%	100.0%	25.0%						
Alkalinity		58.3%	55.6%	26.6%		57.1%	100.0%	100.0%				100.0%	33.3%	52.2%	55.7%	33.7%	35.6%	36.9%

when including them. A more accurate method of determining the minimum instream flow is not applicable due to the lack of habitat data and stream characteristics (cross-sections).

Chapter 4

Results and Conclusions

4.1 General

All of the sites considered in this study have been evaluated in sets by the water body they are associated with. The sites were also compared by their variance and confidence interval width. For conclusion purposes, it was assumed all sites were sampled at monthly intervals. This assumption was made despite the actuality that most of the data was not evenly spaced at this interval. Monthly intervals were used because the few samples spaced at an evident interval were at monthly intervals. Furthermore, samples taken at roughly monthly intervals show neither the effects of seasonality or serial correlation (Loftis and Ward, 1980). Essentially, the effects from seasonality and serial correlation cancel each other out.

4.2 Streams

4.2.1 Little Yellow Creek

The width for pH was significantly larger at sites RS and KY18 (***Figure 7)***. Turbidity had large widths at KY18, YC5A, YC6, and YC12 (***Figure 8)***. Large widths were calculated for TSS at YC5A, YC6, and YC12. Dissolved oxygen had a large confidence interval width at site KY18. Nitrate had a large width at site YC1. Phosphorus at sites YC6 and YC12 had large widths. These water quality variables would yield smaller confidence interval widths if sampled at a higher interval than the current one. Examples of the comparisons and the size difference between confidence interval widths used to make recommendations are shown in ***Figures 7***, ***8***, and ***9.*** All other parameters should continue to be monitored at the current interval (monthly).

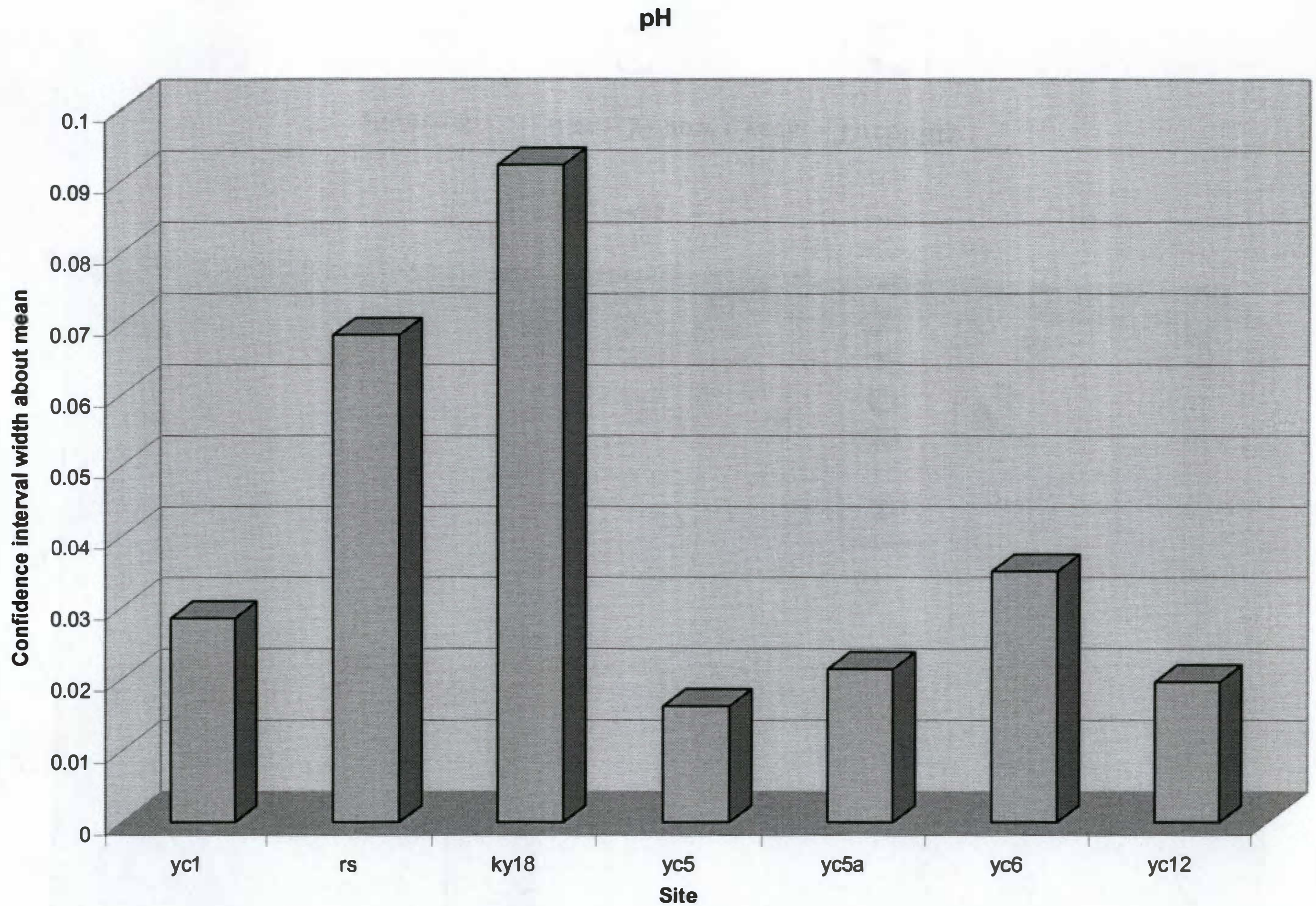


Figure 7. **Little Yellow Creek – pH**

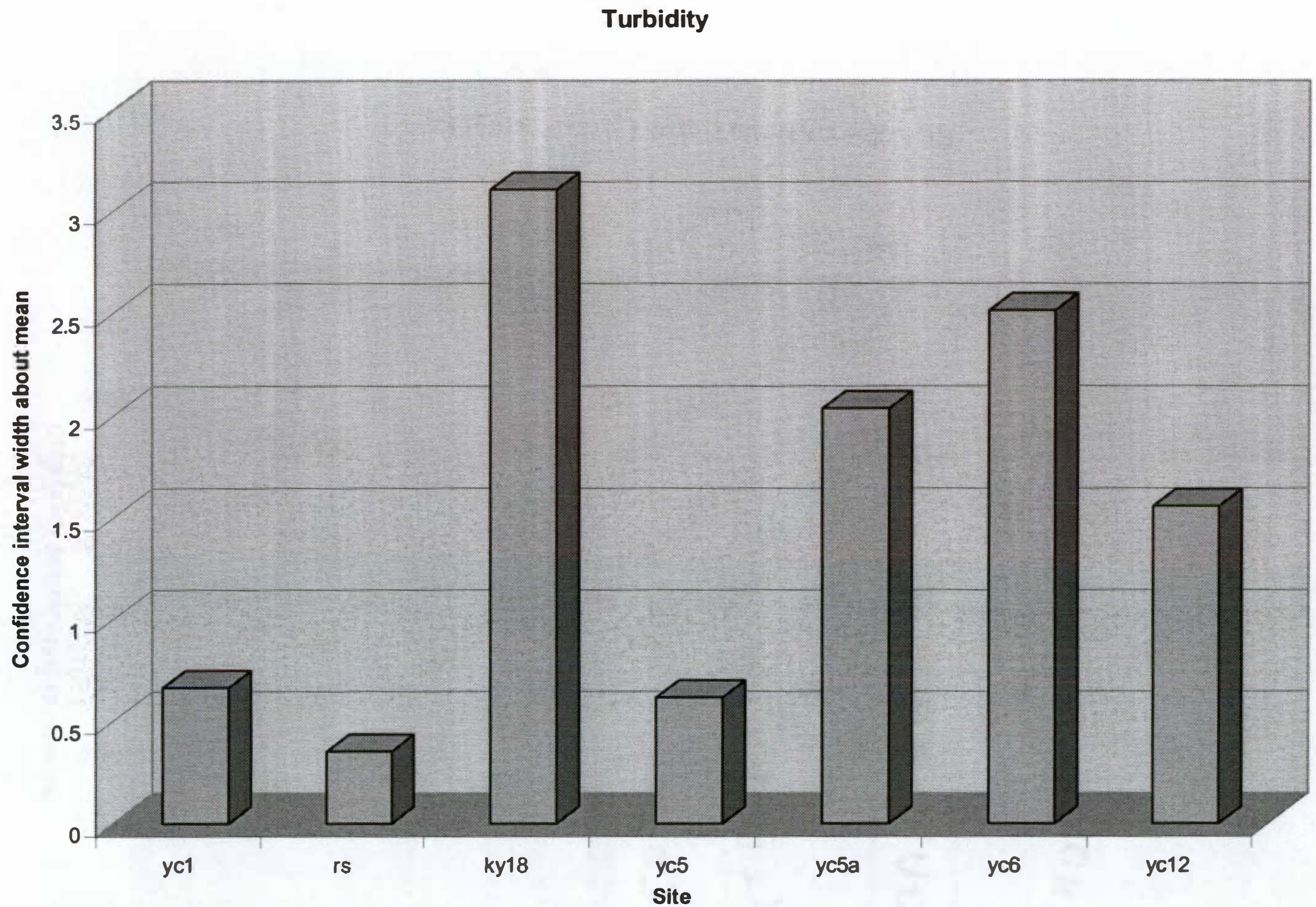


Figure 8. Little Yellow Creek – Turbidity

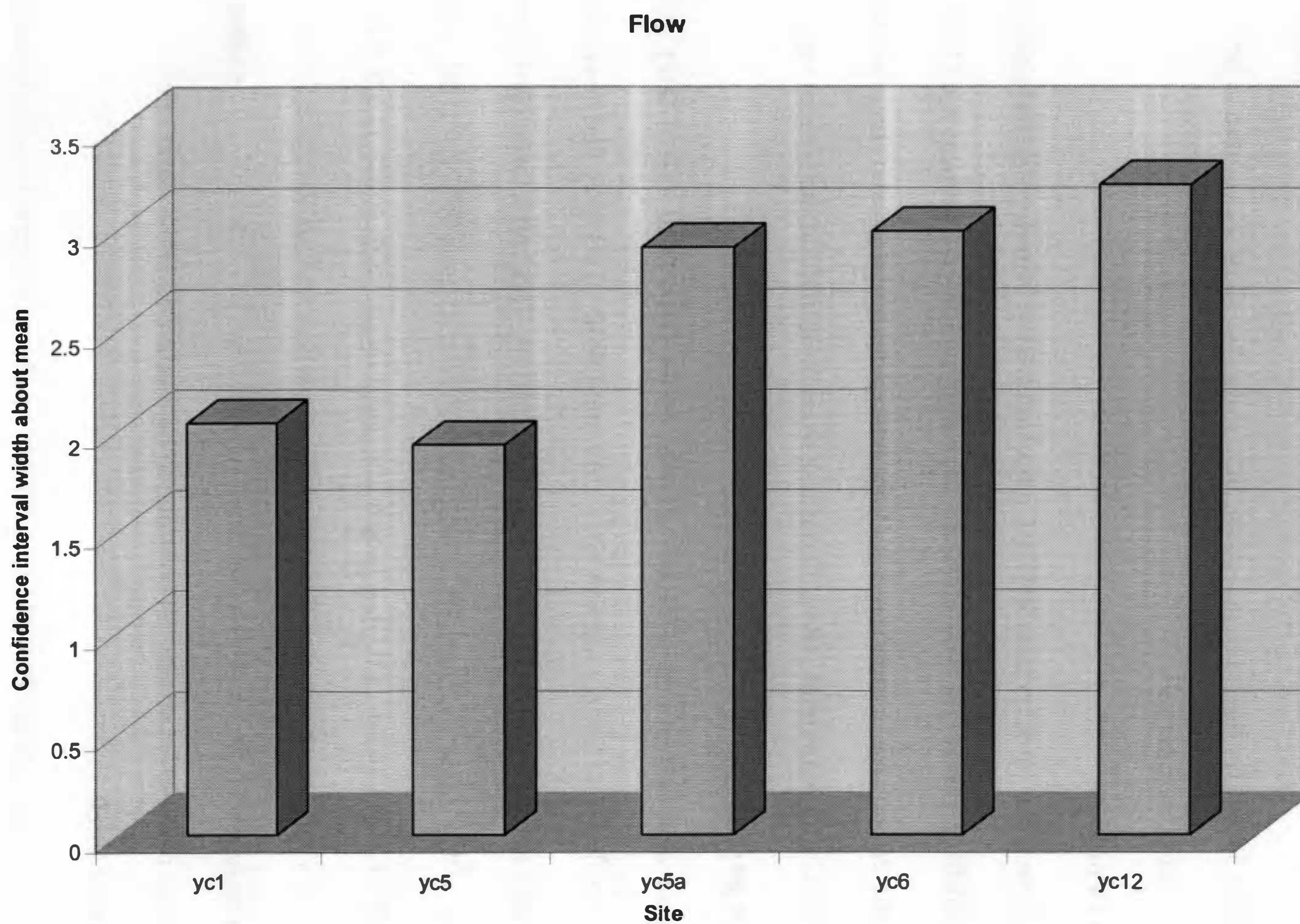


Figure 9. Little Yellow Creek - Streamflow

4.2.2 Martins Fork

Examining the normalized confidence interval widths of each parameter, dissolved oxygen and nitrate had larger widths for site MF2. Site MF5 had confidence interval widths larger for hardness and alkalinity. All other should continue to be monitored at monthly intervals.

4.2.3 Clear Fork

Sites on Clear Fork include SH10, Cudjo, and SR10. Nitrate, pH, and phosphorus had large widths at site SH10. Hardness and alkalinity had large widths at stie Cudjo. These parameters should be monitored at a frequency equal to or greater than the current one. The remaining parameters should continue to be monitored at the current rate.

4.2.4 Davis Branch

The sites on or near Davis Branch are 988, 988B, DB5, DB9, DB10, RR1, and RR10. Streamflow had large widths at sites DB9 and DB10. Turbidity had confidence interval widths at sites RR1 and RR10. Also at site RR10, TSS had a large confidence interval width. Hardness widths were significantly greater at sites 988 and DB9. Nitrate widths were large at 988 and RR10. Phosphorus had a large width solely at site RR10. Alkalinity had large widths at sites 988 and DB9. As with previous variables, these parameters should be monitored at a continual monthly rate or preferably more often. The remaining parameters should all continue to be monitored at the same rate.

4.2.5 Tunnel Creek

For the single site on Tunnel Creek, TC10, confidence interval widths between parameters were compared. Flow, TSS, and turbidity had confidence interval widths substantially greater than those for flow, pH, hardness, dissolved oxygen nitrate, nitrite, and phosphorus. Those parameters with the wider confidence intervals should be monitored at intervals greater than the present to decrease the variability of the data sets for these parameters.

4.2.6 Gap Creek

Sites relating to Gap Creek include GC3, GC4, GC4A, GC5, GC7, IF, Stor1, Tunnel, and Cave (tunnel cave). Dissolved oxygen and streamflow had large widths at GC7. Turbidity had large widths at sites GC5 and Stor1. Site IF had a TSS width substantially larger than other sites for Gap Creek. At site GC4A, hardness and alkalinity was calculated to have large widths. Nitrite had large widths at sites TD1 and GC7, and nitrate had a large width at Stor1. Phosphorus was calculated with large confidence interval widths at sites IF and GC4A.

4.2.7 Station Creek

The sole site attributed to Station Creek is ST10. As with Tunnel Creek, parameters were compared between each other. At this site, all parameters except dissolved oxygen and pH had confidence interval widths magnitudes greater than the other site parameters. In turn, all of these parameters should be monitored at a greater frequency to decrease the confidence interval widths of the data and to achieve a more uniform variability throughout the watershed.

4.2.8 Lewis Hollow

Lewis Hollow has one site, LH5, related to it. Again, parameters were compared between each other. TSS, nitrate, and alkalinity had normalized confidence interval widths magnitudes greater than the other parameters. Hardness and pH had values less than 1. As a result, TSS, nitrate, and alkalinity should have more samples collected per year.

4.3 Standard Exceedances

4.3.1 pH

Sample sites MF2, MF5, and RS were characterized by consistently low pH (between 3.5 and 5.5). SH10 and RR10 also displayed standard exceedances though not to the same percentage of samples (less than 25%) as MF2, MF5, and RS. Also, the data revealed several water quality samples at RR10 in the course of two days with pH values above 10. These samples were the only points in the record for RR10 with high pH values. It is unknown why several samples were taken in such a short time period. Low pH levels are possibly the result of tributary contributions in the network. Drainage from abandoned coal mines is a contributing factor in this area, and this drainage has significantly low pH compared to natural, unaffected streams in the region.

4.3.2 Metals

For chromium, YC1 and YC6 showed some levels exceeding the acceptable constraints. Levels were found at 0.02 mg/L and as high as 0.09 mg/L. High levels of copper (greater than 0.013 mg/L) were also present throughout the monitoring network. Fish toxicity to copper is somewhat dependent on reductions in hardness from normal levels, dissolved oxygen, and the species of fish (Alabster et al, 1982). Therefore, copper levels could be considered a problem to the Little Yellow Creek watershed. Little Yellow Creek displays low levels of alkalinity and dissolved oxygen. Therefore, the copper could potentially be toxic to some aquatic life in the stream. Cadmium was present at sites on Little Yellow Creek, YC1, YC5, YC5A, and YC6, in significant quantities, greater than 0.0043 mg/L. Mercury was also measured at YC1 at levels exceeding standards, greater 0.0014 mg/L. It is not surprising traces of several different metals have been measured on Little Yellow Creek. Mining activities in the area have increased levels of metals in the creek (Liddle, 1995).

4.3.3 Dissolved Oxygen

The range of dissolved oxygen concentrations considered safe for fish is greater than 5 mg/L (EPA, 2002). Dissolved oxygen percentage of saturated quantities considered safe for fish are greater than 60%. Dissolved oxygen was recorded at significantly low levels (as low as 3.2) at site YC5. Dissolved oxygen percentage of saturated measurements were as low as 28.1 for sites DB9, DB10, SH10, YCl, and YC12. Low dissolved oxygen levels are likely the result of discharges in the fall months from the Fern Lake reservoir for the Little Yellow Creek sites. Typically, warmer waters are discharged during these months, and BOD can further lower oxygen levels for reservoirs in this area. This is further reinforced by significant correlations calculated between temperature and dissolved oxygen on Little Yellow Creek.

4.3.4 Alkalinity

Alkalinity was measured at levels lower than criteria for most of the sites in the watershed. The occurrence of these low levels is probably due to the acid mine drainage from the abandoned coal mines in the area.

4.3.5 Other Parameters

The remaining parameters identified above and in ***Appendix A*** (nitrogen, phosphorus, temperature, turbidity, hardness, and alkalinity) were within acceptable limits. The occasional exceedance of water quality criteria was noted, but no pattern of statistical significance was found.

4.4 Final Conclusions

The foremost conclusion drawn from this study is the need for consistent monitoring at each site in the park. The few sampling intervals existent in the data are in the biweekly to monthly range. However, months and years of data are missing intermittently throughout the data. A previous study has shown the effects of seasonality and serial correlation tend to cancel each other out for sampling intervals between 12 to 34 days, which characterize most of the existent intervals in the database (Loftis and Ward, 1980). Therefore, the analysis performed in this study may be adequate to describe the informational content of the historic sampling performed in the Park. A more robust evaluation of the sampling network would be possible with an evenly spaced, extensive record of data. Samples taken at a given interval will allow future analysis to be more conclusive. ***Table 5*** gives a summary of the parameters suggested for more frequent sampling. For the purpose of future monitoring, monthly sampling at the identified locations is recommended.

Streamflow is important to future management of not only the fish habitat but also the ecosystems on Little Yellow Creek. Simulating natural variations in flow is especially important. Flow control via dams or other structures tends to allow a minimum base flow with rare larger flows. However, ecosystems have evolved to the rhythms of variation in hydrology (Baron et al., 2003). Therefore, maintaining some semblance of this natural variation is a suggested objective of any future flow control.

Using the Tennant method (1976), the minimum flow for 'short-term' survival of

Table 5. Parameters Suggested for More Frequent Sampling

Site	Due to Exceedances	Due to CI widths
988		Hardness, Nitrate, Alkalinity
DB5	Alkalinity	
DB9	DO, Alkalinity	Flow, Alkalinity, Hardness
DB10	DO, Alkalinity	Flow
GC4A		Hardness, Alkalinity, Phosphorus
GC5		Turbidity
GC7		Flow, Nitrite, Dissolved Oxygen
IF		TSS, Phosphorus
KY18	DO	Turbidity, pH, Dissolved Oxygen
LH5	Alkalinity	TSS
MF2	pH, Alkalinity	Dissolved Oxygen, Nitrate
MF5	pH, Alkalinity	Hardness, Alkalinity
RR1		Turbidity
RR10	pH	Phosphorus, Turbidity, TSS, Nitrate
RS	pH	pH
SH10	Alkalinity	pH, Nitrate, Phosphorus
ST10	Alkalinity	TSS, Turbidity, Nitrate
STOR1		Turbidity, Nitrate
TC10		Flow, TSS
TD1		Nitrite
YC1	Cadmium, Chromium, Copper, Mercury, DO, Alkalinity	Nitrate
YC5	Cadmium, DO, Alkalinity	
YC5A	Cadmium, Alkalinity	Turbidity
YC6	Cadmium, Chromium, Copper, Alkalinity	Turbidity, Phosphorus
YC12	DO, Alkalinity	Turbidity, Phosphorus

aquatic life was calculated to be 0.66 cubic feet per second (cfs) for Little Yellow Creek. The flow that provides satisfactory protection of aquatic organisms was determined to be. 1.98 cfs for Little Yellow Creek. Considering management of the dam above Little Yellow Creek, flow management would be more applicable with more thorough future studies. A habitat modeling method, such as PHABSIM, of determining the minimum instream flows for Little Yellow Creek is suggested. Use of this method would entail assessment of habitat for aquatic life in the stream and cross-section surveys of the stream The habitat modeling method would allow for determining seasonal minimum instream flows and provide more reliable flows than the Tennant method.

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Appendix

Calculated Statistics

Martins Fork

variance and confidence intervals	mf2	mf5	Network Statistics
DO % sat. variance	49.622	4.309	27.048
normalized var.	0.5278936	0.0458404	0.2877447
DO % sat. mean	85.08	86.575	85.74
CI mean upper limit	93.826639	89.878146	89.74
CI mean lower limit	76.333361	83.271854	81.75
CI width	17.493278	6.606292	7.99
normalized CI width	0.2043607	0.0771763	0.0933411
flow variance			
normalized var.			
flow mean			
CI mean upper limit			
CI mean lower limit			
CI width			
normalized CI width			
ph variance	0.822	0.245	0.59
normalized var.	0.1141667	0.0340278	0.0819444
ph mean	5.2055555	4.6875	4.962
CI mean upper limit	5.902591	5.101641	5.357
CI mean lower limit	4.50852	4.273359	4.567
CI width	1.394071	0.828282	0.79
normalized CI width	0.2838092	0.1686242	0.1608306
turbid variance	3.222	2.449	2.431
normalized var.	0.8055	0.61225	0.60775
turbidity mean	1.325	1.275	1.3
CI mean upper limit	4.181456	3.765235	2.6
CI mean lower limit	-1.531456	-1.215235	0
CI width	5.712912	4.98047	2.6
normalized CI width	2.3509926	2.0495761	1.0699588

Martins Fork continued

variance and confidence intervals	mf2	mf5	Network Statistics
TSS variance	13.586	3.996	8.711
normalized var.	1.5095556	0.444	0.9678889
TSS mean	4.9044	3.675	4.36
CI mean upper limit	9.481106	6.855788	6.63
CI mean lower limit	0.327694	0.494212	2.09
CI width	9.153412	6.361576	4.54
normalized CI width	3.8785644	2.6955831	1.9237288
temp variance	10.682	16.958	11.899
normalized var.	0.7684892	1.22	0.8560432
temperature mean	9.402	10.2475	9.778
CI mean upper limit	13.460137	16.800215	12.429
CI mean lower limit	5.343863	3.694785	7.126
CI width	8.116274	13.10543	5.303
normalized CI width	0.8915064	1.4395244	0.5824912
hard variance	0.087	0.537	0.302
normalized var.	0.0174	0.1074	0.0604
hardness mean	4.1	3.75	3.93
CI mean upper limit	4.568443	4.915691	4.38
CI mean lower limit	3.631557	2.584309	3.47
CI width	0.936886	2.331382	0.91
normalized CI width	0.2408447	0.599327	0.2339332
Nitrite variance			
normalized var.			
nitrite mean			
CI mean upper limit			
CI mean lower limit			
CI width			
normalized CI width			

Martins Fork continued

variance and confidence intervals	mf2	mf5	Network Statistics
nitrate variance	0.722	0.122	0.435
normalized var.	0.3281818	0.0554545	0.1977273
nitrate mean	0.995	0.4875	0.741
CI mean upper limit	2.34729	1.04274	1.293
CI mean lower limit	-0.35729	-0.06774	0.19
CI width	2.70458	1.11048	1.103
normalized CI width	5.7300424	2.3527119	2.3368644
P variance			
normalized var.			
P mean			
CI mean upper limit			
CI mean lower limit			
CI width			
normalized CI width			
alk variance	0.009	0.203	0.094
normalized var.	0.009	0.203	0.094
alkalinity mean	0.225	0.325	0.28
CI mean upper limit	0.377348	1.04105	0.53
CI mean lower limit	0.072652	-0.39105	0.02
CI width	0.304696	1.4321	0.51
normalized CI width	1.6036632	7.5373684	2.6842105

Note: Sites in order from upstream to downstream as go left to right

Davis Branch

variance and confidence intervals	db5	988	988B	rr1	db9	rr10	db10	Network Statistics
DO % sat. variance			51.983	401.714	873.918	1243.79	675.968	841.153
normalized var.			0.4813241	3.7195741	8.0918333	11.516574	6.258963	7.7884537
DO % sat. mean			95.563633	89.64	70.105135	74.021364	72.47093	76.994512
CI mean upper limit			100.4073	97.124102	79.961633	84.743633	80.472362	81.466495
CI mean lower limit			90.719965	82.155898	60.248637	63.299094	64.469498	72.52253
CI width			9.687335	14.968204	19.712996	21.444539	16.002864	8.943965
normalized CI width			0.1514837	0.2340621	0.3082578	0.3353345	0.2502414	0.1398594
flow variance				0.031	0.153	0.032	0.186	0.315
normalized var.				0.007381	0.0364286	0.007619	0.0442857	0.075
flow mean				0.083354	0.287012	0.126209	0.2658475	0.245292
CI mean upper limit				0.189121	0.488119	0.205826	0.462254	0.373519
CI mean lower limit				-0.022413	0.085905	0.046592	0.069441	0.117066
CI width				0.211534	0.402214	0.159234	0.392813	0.256453
normalized CI width				5.2491129	9.9807439	3.9513139	9.7474627	6.3637559
ph variance	0.189	0.017	0.094	0.149	0.497	0.936	0.135	1.214
normalized var.	0.0181208	0.0016299	0.0090125	0.0142857	0.047651	0.0897411	0.0129434	0.116395
ph mean	7.0625	7.704765	7.785	7.58093	6.8661705	7.9014815	7.309605	7.321568
CI mean upper limit	7.24627	7.76494	7.979357	7.648148	7.073091	8.165509	7.368563	7.424803
CI mean lower limit	6.87873	7.64459	7.590643	7.513712	6.65925	7.637454	7.250647	7.218333
CI width	0.36754	0.12035	0.388714	0.134436	0.413841	0.528055	0.117916	0.20647
normalized CI width	0.0530842	0.0173823	0.0561424	0.0194167	0.0597715	0.0762675	0.0170307	0.0298207
turbid variance			4.383	275.852	13.914	1290.003	98.924	468.974
normalized var.			0.0184781	1.1629511	0.0586594	5.4384612	0.4170489	0.2838239
turbidity mean			3.509091	18.564286	7.733333	15.478049	9.9243245	13.243448
CI mean upper limit			4.91555	25.004503	9.126194	26.814731	13.240506	16.798154
CI mean lower limit			2.102632	12.124068	6.340472	4.141366	6.608143	9.688743
CI width			2.812918	12.880435	2.785722	22.673365	6.632363	7.109411
normalized CI width			0.3185998	1.4588781	0.3155195	2.5680558	0.7512021	0.805234

Davis Branch continued

variance and confidence intervals	db5	988	988B	rr1	db9	rr10	db10	Network Statistics
TSS variance	97.337	21113.153		6493.47	182.608	9744.728	390.122	4342.701
normalized var.	0.1557392	33.781045		10.389552	0.2921728	15.591565	0.6241952	6.9483216
TSS mean	8.6002095	22.888095		27.113434	4.7921055	39.2373	9.2614875	24.110364
CI mean upper limit	12.914187	43.81295		43.185244	11.305282	105.5552	12.816632	31.93356
CI mean lower limit	4.286232	1.96324		11.041624	-1.721071	-27.0806	5.706343	16.287167
CI width	8.627955	41.84971		32.14362	13.026353	132.6358	7.110289	15.646393
normalized CI width	1.2654671	6.1381211		4.7145233	1.9105827	19.453769	1.0428702	2.2948655
temp variance			14.238	37.299	34.045	12.288	39.982	28.857
normalized var.			0.5413688	1.4182129	1.2944867	0.4672243	1.5202281	1.0972243
temperature mean			11.629091	12.632667	11.182895	12.213334	12.984773	12.218929
CI mean upper limit			14.164039	14.913168	13.100753	13.266465	14.907181	13.037167
CI mean lower limit			9.094143	10.352166	9.265036	11.160202	11.062364	11.40069
CI width			5.069896	4.561002	3.835717	2.106263	3.844817	1.636477
normalized CI width			0.4728939	0.4254269	0.357776	0.1964614	0.3586248	0.1526422
hard variance	86.418	7771		215.391	1546.874	128.645	1480.22	3137.998
normalized var.	0.2033365	18.284706		0.5068024	3.6397035	0.3026941	3.4828706	7.3835247
hardness mean	19.280953	211.5		71.248959	35.677778	91.755538	61.224057	73.505534
CI mean upper limit	23.51249	252.757		74.222635	65.909742	100.4739	68.633617	80.320164
CI mean lower limit	15.049415	170.243		68.275282	5.445814	83.037176	53.814496	66.690904
CI width	8.463075	82.514		5.947353	60.463928	17.436724	14.819121	13.62926
normalized CI width	0.147448	1.4376013		0.1036178	1.0534336	0.3037916	0.2581863	0.237456
Nitrite variance	0.137	0.216						0.075
normalized var.	0.0752747	0.1186813						0.0412088
nitrite mean	0.191818	0.188095						0.065836
CI mean upper limit	0.355736	0.39958						0.091736
CI mean lower limit	0.0279	-0.02339						0.039937
CI width	0.327836	0.42297						0.051799
normalized CI width	13.774622	17.771849						2.1764286

Davis Branch continued

variance and confidence intervals	db5	988	988B	rr1	db9	rr10	db10	Network Statistics
nitrate variance	0.131	170.4		0.285	0.534	20.76	0.76	25.488
normalized var.	0.0023818	3.0981818		0.0051818	0.0097091	0.3774545	0.0138182	0.4634182
nitrate mean	0.4331815	12.99857		0.914796	0.71625	3.1711115	0.6875925	1.912794
CI mean upper limit	0.593845	18.94056		1.021739	1.327027	6.673372	0.85385	2.515453
CI mean lower limit	0.272518	7.05658		0.807853	0.105473	-0.331149	0.521335	1.310135
CI width	0.321327	11.88398		0.213886	1.221554	7.004521	0.332515	1.205318
normalized CI width	0.5021519	18.571621		0.3342491	1.9089764	10.946274	0.5196359	1.8836037
P variance	0	0		0	0	0.001	0	0.005
normalized var.	0	0	0	0	0	0.0011364	0	0.0056818
P mean	0.09375	0.09286		0.09702	0.0977775	0.0894445	0.0968345	0.105607
CI mean upper limit	0.100883	0.10102		0.099734	0.102902	0.113786	0.099446	0.114459
CI mean lower limit	0.086617	0.0847		0.094306	0.092653	0.065103	0.094223	0.096754
CI width	0.014266	0.01632		0.005428	0.010249	0.048683	0.005223	0.017705
normalized CI width	0.1483893	0.1697542		0.0564599	0.1066061	0.5063814	0.0543276	0.1841604
alk variance	119.185	1777.648		122.25	1214.953	78.369	1094.274	1225.104
normalized var.	0.54175	8.0802182		0.5556818	5.5225136	0.3562227	4.9739727	5.5686545
alkalinity mean	16.004167	119.95219		39.461225	29.12	57.811112	46.227523	47.109485
CI mean upper limit	20.614086	139.14437		41.677945	55.912824	64.615826	52.507982	51.287731
CI mean lower limit	11.394247	100.76		37.244504	2.327176	51.006397	39.947064	42.93124
CI width	9.219839	38.38437		4.433441	53.585648	13.609429	12.560918	8.356491
normalized CI width	0.2541406	1.0580473		0.1222057	1.4770635	0.3751376	0.3462359	0.2303428

Note: Sites in order from upstream to downstream as go left to right. Davis Branch flows into Little Yellow Creek

Little Yellow Creek

variance and confidence intervals	yc1	rs	ky18	yc5	yc5a	yc6	yc12	Network Statistics
DO % sat. variance	527.041	32.343	915.503				508.689	5321.478
normalized var.	4.7782502	0.2932276	8.3001179				4.6118676	48.245494
DO % sat. mean	70.589362	94.860022	49.12353				73.748276	75.905051
CI mean upper limit	77.329896	101.9215	64.680389				82.32741	90.454365
CI mean lower limit	63.848827	87.798544	33.56667				65.169142	61.355736
CI width	13.481069	14.122956	31.113719				17.158268	29.098629
normalized CI width	0.222526	0.2331213	0.5135803				0.2832239	0.4803181
DO variance	3.584			5.893	3.167	3.093	2.798	4.01
normalized var.	0.2778295			0.4568217	0.2455039	0.2397674	0.2168992	0.3108527
DO mean	8.693103			7.5705885	8.6295235	8.839655	8.629213	8.405825
CI mean upper limit	9.190868			8.047404	8.973906	9.302103	8.981605	8.599749
CI mean lower limit	8.195339			7.093773	8.285141	8.377207	8.276822	8.211902
CI width	0.995529			0.953631	0.688765	0.924896	0.704783	0.387847
normalized CI width	0.1221508			0.1170099	0.084511	0.1134842	0.0864764	0.0475886
flow variance	58.208			61.105	150.702	91.788	193.418	141.856
normalized var.	0.5879596			0.6172222	1.5222424	0.9271515	1.9537172	1.4328889
flow mean	4.2645982			4.548701	6.979759	7.2208165	8.3757045	6.591018
CI mean upper limit	6.140141			6.322939	9.660313	9.972685	11.33979	7.82036
CI mean lower limit	2.3890553			2.774463	4.299205	4.468948	5.411619	5.361677
CI width	3.7510857			3.548476	5.361108	5.503737	5.928171	2.458683
normalized CI width	2.0378583			1.9277862	2.9125376	2.9900239	3.2206068	1.3357326
ph variance	0.292	0.037	0.478	0.149	0.269	0.222	0.158	0.365
normalized var.	0.0293763	0.0037223	0.0480885	0.0149899	0.0270624	0.022334	0.0158954	0.0367203
ph mean	6.7913045	3.8	7.3695	6.873481	7.3812835	7.062712	7.145303	7.050229
CI mean upper limit	6.891101	4.039966	7.693065	6.930025	7.45607	7.185604	7.213803	7.095091
CI mean lower limit	6.691508	3.560034	7.045935	6.816937	7.306497	6.93982	7.076803	7.005367
CI width	0.199593	0.479932	0.64713	0.113088	0.149573	0.245784	0.137	0.089724
normalized CI width	0.0284245	0.0683483	0.0921594	0.0161051	0.0213011	0.0350027	0.0195105	0.0127778

Little Yellow Creek continued

variance and confidence intervals	yc1	rs	ky18	yc5	yc5a	yc6	yc12	Network Statistics
turbid variance	153.771	1.067	486.029	121.546	1388.78	1217.971	956.597	772.758
normalized var.	0.768855	0.005335	2.430145	0.60773	6.9439	6.089855	4.782985	3.86379
turbidity mean	9.049029	1.02	17.947059	8.06	21.704041	17.551724	18.335345	15.267798
CI mean upper limit	11.472567	2.302585	29.282099	10.305867	29.13668	26.728064	24.023584	17.745431
CI mean lower limit	6.625491	-0.262585	6.612019	5.814133	14.271401	8.375384	12.647106	12.790165
CI width	4.847076	2.56517	22.67008	4.491734	14.865279	18.35268	11.376478	4.955266
normalized CI width	0.664165	0.3514894	3.1063415	0.6154747	2.0368976	2.5147547	1.5588487	0.6789896
TSS variance	37.82			54.678	696.061	257.944	557.615	1728.247
normalized var.	0.0717647			0.1037533	1.3207989	0.4894573	1.058093	3.2794061
TSS mean	4.1085715			5.776125	13.256066	8.7538465	13.733862	13.18982
CI mean upper limit	5.755501			6.930677	17.104141	13.225154	18.395536	16.652894
CI mean lower limit	2.461642			4.621573	9.40799	4.282539	9.072187	9.726747
CI width	3.293859			2.309104	7.696151	8.942615	9.323349	6.926147
normalized CI width	0.7328787			0.5137722	1.7123822	1.9897186	2.0744313	1.5410574
temp variance	43.923	3.129	23.872	34.007	24.663	30.28	41.872	34.979
normalized var.	1.519827	0.1082699	0.8260208	1.1767128	0.853391	1.0477509	1.4488581	1.210346
temperature mean	13.808396	13.364	12.412353	14.787255	14.633333	14.022414	15.17695	14.462818
CI mean upper limit	15.084768	15.560458	14.924465	15.932685	15.59442	15.469291	16.356685	14.97683
CI mean lower limit	12.532024	11.167542	9.90024	13.641825	13.672246	12.575537	13.997214	13.948806
CI width	2.552744	4.392916	5.024225	2.29086	1.922174	2.893754	2.359471	1.028024
normalized CI width	0.1959995	0.3372878	0.3857596	0.1758921	0.1475844	0.2221822	0.18116	0.0789316
hard variance	83.321			301.438	1103.58	691.853	1161.574	882.743
normalized var.	0.4005817			1.4492212	5.3056731	3.3262163	5.5844904	4.2439567
hardness mean	22.818358			29.377667	53.709511	45.99	56.566634	42.661568
CI mean upper limit	25.044857			31.931291	58.541464	52.906046	63.294823	45.057789
CI mean lower limit	20.591859			26.824043	48.877558	39.073954	49.838444	40.265348
CI width	4.452998			5.107248	9.663906	13.832092	13.456379	4.792441
normalized CI width	0.1295742			0.1486117	0.2812022	0.4024889	0.3915563	0.1394514

Little Yellow Creek continued

variance and confidence intervals	ycl	rs	ky18	yc5	yc5a	yc6	yc12	Network Statistics
Nitrite variance	0.001			0.013	0.007	0.002	0.001	0.006
normalized var.	0.001052632			0.013684211	0.007368421	0.002105263	0.001052632	0.006315789
nitrite mean	0.026232			0.0402745	0.0440105	0.0338985	0.0270875	0.037169
CI mean upper limit	0.034565			0.056742	0.055775	0.044255	0.032606	0.043557
CI mean lower limit	0.017899			0.023807	0.032246	0.023542	0.021569	0.03078
CI width	0.016666			0.032935	0.023529	0.020713	0.011037	0.012777
normalized CI width	0.696637198			1.376679834	0.983509938	0.865801409	0.461345539	0.534077372
nitrate variance	0.696			0.559	0.241	0.08	0.115	0.661
normalized var.	0.071752577			0.057628866	0.024845361	0.008247423	0.01185567	0.06814433
nitrate mean	0.3115385			0.3616775	0.4541765	0.2336955	0.3864895	0.430587
CI mean upper limit	0.582021			0.480349	0.528557	0.317508	0.455974	0.501271
CI mean lower limit	0.041056			0.243006	0.379796	0.149883	0.317005	0.359903
CI width	0.540965			0.237343	0.148761	0.167625	0.138969	0.141368
normalized CI width	2.625916218			1.152094559	0.722105723	0.813674093	0.67457405	0.686219116
P variance	0.005			0.002	0.006	0.037	0.029	0.018
normalized var.	0.002617801			0.00104712	0.003141361	0.019371728	0.015183246	0.009424084
P mean	0.0925835			0.097343	0.106241	0.1638635	0.141402	0.11659
CI mean upper limit	0.112154			0.104984	0.117607	0.22258	0.176911	0.128055
CI mean lower limit	0.073013			0.089702	0.094875	0.105147	0.105893	0.105124
CI width	0.039141			0.015282	0.022732	0.117433	0.071018	0.022931
normalized CI width	0.446927311			0.174495878	0.259562904	1.340896115	0.810911416	0.261835164
alk variance	125.229			340.148	731.109	332.373	613.311	576.036
normalized var.	0.894492857			2.429628571	5.222207143	2.374092857	4.380792857	4.114542857
alkalinity mean	18.011594			20.6483515	37.2967915	32.4288135	38.651923	30.089404
CI mean upper limit	20.699864			23.345841	41.19759	37.179862	43.468119	32.007308
CI mean lower limit	15.323324			17.950862	33.395993	27.677765	33.835727	28.1715
CI width	5.37654			5.394979	7.801597	9.502097	9.632392	3.835808
normalized CI width	0.256087907			0.256966168	0.371594864	0.452590724	0.458796755	0.182701894

Gap Creek

variance and confidence intervals	if	td1	gc3	gc4	gc4a	gc5	tunnel	gc7	stor1	tunlcave	Network Statistics
DO % sat. variance	966.132			661.004	908.195	16.622		736.494	40.896		856.893
normalized var.	6.876384			4.7046548	6.46402135	0.11830605		5.241950178	0.291074733		6.098882562
DO % sat. mean	83.70435			79.576905	81.3138095	97.8200125		86.786654	91.825		81.746087
CI mean upper limit	92.93476			87.588703	90.704935	102.8823		101.8154	97.17138		86.302214
CI mean lower limit	74.47394			71.565107	71.922684	92.757725		71.757908	86.47862		77.18996
CI width	18.46082			16.023596	18.782251	10.124575		30.057492	10.69276		9.112254
normalized CI width	0.272003			0.23609247	0.27673863	0.149175998		0.442868602	0.157547665		0.13426041
flow variance	6.335			0.695	8.633			3.984			5.274
normalized var.	0.487308			0.05346154	0.66407692			0.306461538			0.405692308
flow mean	1.83646			0.334229	1.400618			1.229375			1.195521
CI mean upper limit	2.875429			0.686203	2.703353			4.40536			1.723905
CI mean lower limit	0.797491			-0.017745	0.097883			-1.94661			0.667138
CI width	2.077938			0.703948	2.60547			6.35197			1.056767
normalized CI width	9.976225			3.37966959	12.5089179			30.49594554			5.073561254
ph variance	0.661	0.062	0.04	0.163	0.243	0.041	0.05	0.053	0.091	0.05	1.841
normalized var.	0.0623	0.00584354	0.00377	0.01536287	0.02290292	0.003864279	0.004712535	0.004995287	0.008576814	0.004712535	0.173515551
ph mean	8.174407	7.7505375	7.8544445	7.916702	7.952	7.848333	7.8666665	7.7992	7.531875	7.8666665	7.643411
CI mean upper limit	8.386265	7.801856	7.896235	7.999421	8.091981	8.060144	7.94254	7.83989	7.640495	8.008308	7.752375
CI mean lower limit	7.962548	7.699219	7.812654	7.833983	7.812019	7.636522	7.790793	7.75851	7.423255	7.725025	7.534448
CI width	0.423717	0.102637	0.083581	0.165438	0.279962	0.423622	0.151747	0.08138	0.21724	0.283283	0.217927
normalized CI width	0.061075	0.01479431	0.0120475	0.02384658	0.0403543	0.06106175	0.021873126	0.011730281	0.031313423	0.040832997	0.031412448
turbid variance	40.891			18.697	40.075	33.995		19.523	1640.458		143.605
normalized var.	0.324532			0.14838889	0.31805556	0.269801587		0.154944444	13.01950794		1.139722222
turbidity mean	7.559091			5.8	7.6675	7.1666665		7.49375	20.133329		8.729139
CI mean upper limit	9.503225			7.164824	9.692088	13.285395		9.848211	51.266358		10.656055
CI mean lower limit	5.614956			4.435176	5.642912	1.047938		5.139289	-10.9997		6.802223
CI width	3.888269			2.729648	4.049176	12.237457		4.708922	62.266058		3.853832
normalized CI width	0.63427			0.4452713	0.66051809	1.996223841		0.768138541	10.15709305		0.628652776

Gap Creek continued

variance and confidence intervals	if	td1	gc3	gc4	gc4a	gc5	tunnel	gc7	stor1	tunlcave	Network Statistics
TSS variance	10896.802	976.195	349.975	2974.478	841.213		21.052	656.228	2827.005	229.981	2370.718
normalized var.	28.6005302	2.5621916	0.91856955	7.80702887	2.20790814		0.0552546	1.722383202	7.41996063	0.603624672	6.222356955
TSS mean	50.3132	14.460215	8.7277775	17.111905	9.3057895		3.601429	14.134955	29.25	9.65	21.051964
CI mean upper limit	113.3941	20.894865	12.646011	30.847318	23.285114		5.177557	18.953526	51.701548	19.285458	25.619243
CI mean lower limit	-12.7677	8.025565	4.809544	3.376492	-4.673535		2.025301	9.316384	6.798452	0.014542	16.484684
CI width	126.1618	12.8693	7.836467	27.470826	27.958649		3.152256	9.637142	44.903096	19.270916	9.134559
normalized CI width	21.9683508	2.2409105	1.36455136	4.78345063	4.86839446		0.5488973	1.678099995	7.818903691	3.355613525	1.590586027
temp variance	11.014			18.73	13.241	1.08		15.645	4.569		14.33
normalized var.	0.49859665			0.84789498	0.5994115	0.0488909		0.708239022	0.206835672		0.648709823
temperature mean	12.982653			13.662727	12.63	13.552		13.868667	12.26625		13.05797
CI mean upper limit	13.935916			14.978521	13.74985	14.842178		16.059082	14.053212		13.639857
CI mean lower limit	12.02939			12.346933	11.51015	12.261822		11.678252	10.479288		12.476082
CI width	1.906526			2.631588	2.2397	2.580356		4.38083	3.573924		1.163775
normalized CI width	0.15500211			0.21395024	0.18208943	0.20978504		0.356165041	0.290562927		0.094615854
hard variance	378.393	791.884	333.475	4070.026	11182.182		614.257	1341.213	7857.237	133.636	2723.996
normalized var.	0.90093571	1.8854381	0.7939881	9.6905381	26.6242429		1.4625167	3.193364286	18.70770714	0.318180952	6.485704762
hardness mean	72.4	147.8778	71.781609	182.6636	97.128556		116.83335	108.50275	132.347829	99.999975	118.4701
CI mean upper limit	87.352372	153.7717	75.67362	201.395	128.9274		125.2191	115.4887	170.6791	107.3449	123.4821
CI mean lower limit	57.447628	141.9839	67.889598	163.9322	65.329712		108.4476	101.5168	94.016558	92.65505	113.4582
CI width	29.904744	11.7878	7.784022	37.4628	63.597688		16.7715	13.9719	76.662542	14.68985	10.0239
normalized CI width	0.27930843	0.1100973	0.07270228	0.3499002	0.59399842		0.1566448	0.13049667	0.716023335	0.137202278	0.093622597
Nitrite variance		0.016	0.002	0				0.023	0		0.016
normalized var.		0.016	0.002	0				0.023	0		0.016
nitrite mean		0.0527955	0.0249425	0.0212				0.059189	0.0233335		0.044988
CI mean upper limit		0.079198	0.034768	0.023611				0.087822	0.030229		0.056871
CI mean lower limit		0.026393	0.015117	0.018789				0.030556	0.016438		0.033106
CI width		0.052805	0.019651	0.004822				0.057266	0.013791		0.023765
normalized CI width		2.3221196	0.86416007	0.21204925				2.518293755	0.60646438		1.045074758

Gap Creek continued

variance and confidence intervals	if	td1	gc3	gc4	gc4a	gc5	tunnel	gc7	storl	tunlcave	Network Statistics
nitrate variance	0.426	0.313	0.205	0.696	0.162		1.056	3.14	7.418	0.118	2.656
normalized var.	0.0284	0.0208667	0.0136667	0.0464	0.0108		0.0704	0.209333333	0.494533333	0.007866667	0.177066667
nitrate mean	1.352222	0.31575	0.9270785	1.0436	1.0614285		0.9619445	2.320182	3.5416665	0.545	1.406042
CI mean upper limit	1.854036	0.885468	1.022476	1.280635	1.434224		1.309708	2.655042	4.691723	0.763181	1.560169
CI mean lower limit	0.850408	-0.253968	0.831681	0.806565	0.688633		0.614181	1.985322	2.39161	0.326819	1.251914
CI width	1.003628	1.139436	0.190795	0.47407	0.745591		0.695527	0.66972	2.300113	0.436362	0.308255
normalized CI width	2.26042342	2.5662973	0.4297185	1.06772523	1.679259009		1.566502252	1.508378378	5.180434685	0.982797297	
P variance	0.001	0	0	0	0.001			0.002	0		0.056
normalized var.	0.00035714	0	0	0	0.000357143			0.000714286	0		0.02
P mean	0.0894445	0.097312	0.0974155	0.09491725	0.087143			0.1136975	0.09375		0.137316
CI mean upper limit	0.113786	0.099647	0.099695	0.1000095	0.118603			0.122493	0.100883		0.159785
CI mean lower limit	0.065103	0.094977	0.095136	0.089825	0.055683			0.104902	0.086617		0.114847
CI width	0.048683	0.00467	0.004559	0.0101845	0.06292			0.017591	0.014266		0.044938
normalized CI width	0.46165153	0.0442847	0.0432321	0.09657765	0.596658259			0.16681207	0.135281734		0.426138411
alk variance	430.49	545.09	382.614	1764.031	1208.882		617.266	885.177	2502.579	209.242	1527.472
normalized var.	1.92183036	2.4334375	1.7080982	7.87513839	5.396794643		2.755651786	3.951683036	11.17222768	0.934116071	6.819071429
alkalinity mean	67.3555555	124.82605	63.38	142.196	89.7285615		106.638903	86.6126125	93.1708495	92.166654	98.216204
CI mean upper limit	83.30408	129.6611	67.476869	154.1324	121.8845		115.0452	92.208975	114.2949	101.3574	101.9121
CI mean lower limit	51.407031	119.991	59.283131	130.2596	57.572623		98.232606	81.01625	72.046799	82.975908	94.520356
CI width	31.897049	9.6701	8.193738	23.8728	64.311877		16.812594	11.192725	42.248101	18.381492	7.391744
normalized CI width	0.35332318	0.1071156	0.0907619	0.26443868	0.712381792		0.186232877	0.123981664	0.467981644	0.203611538	0.081878248

Note: Sites in order upstream to downstream as go left to right except Storl and Tunnel Cave which are in the watershed but not directly on the stream.

Clear Fork

variance and confidence intervals	sh10	Cudjo	sr10	Network Statistics
DO % sat. variance	31.903	221.587	237.625	762.93
normalized var.	0.242977913	1.687638995	1.809786748	5.810586443
DO % sat. mean	86.95	90.9833335	94.36669	84.045882
CI mean upper limit	95.937711	98.385873	106.2158	93.683368
CI mean lower limit	77.962289	83.580794	82.51758	74.408397
CI width	17.975422	14.805079	23.69822	19.274971
normalized CI width	0.248760338	0.20488623	0.327957653	0.266744686
flow variance				
normalized var.				
flow mean				
CI mean upper limit				
CI mean lower limit				
CI width				
normalized CI width				
ph variance	1.465	0.086	0.053	2.007
normalized var.	0.15923913	0.009347826	0.00576087	0.218152174
ph mean	6.010833	7.7146875	6.137778	6.976667
CI mean upper limit	6.779821	7.820363	6.314144	7.363319
CI mean lower limit	5.241845	7.609012	5.961412	6.590014
CI width	1.537976	0.211351	0.352732	0.773305
normalized CI width	0.236976271	0.032565639	0.054350077	0.119153313
turbid variance	2402.81	3.777	1121.618	760.54
normalized var.	22.06437098	0.034683196	10.2995225	6.983838384
turbidity mean	26.55	2.1235295	21.833333	13.030769
CI mean upper limit	104.5493	3.122748	47.576455	24.169719
CI mean lower limit	-51.4493	1.124311	-3.909789	1.89182
CI width	155.9986	1.998437	51.486244	22.277899
normalized CI width	37.74909789	0.483588916	12.45882504	5.390885495

Clear Fork continued

variance and confidence intervals	sh10	Cudjo	sr10	Network Statistics
TSS variance	2.901	19.689		79.097
normalized var.	0.073073048	0.495944584		1.992367758
TSS mean	2.154375	2.547222		4.894524
CI mean upper limit	3.57842	4.753802		8.942877
CI mean lower limit	0.73033	0.340642		0.846171
CI width	2.84809	4.41316		8.096706
normalized CI width	1.465217615	2.270377611		4.165400761
temp variance	16.648	0.425	14.654	6.419
normalized var.	0.971295216	0.024795799	0.85495916	0.374504084
temperature mean	12.836	11.7455	10.4488885	11.562647
CI mean upper limit	17.902237	12.050602	13.39135	12.446671
CI mean lower limit	7.769763	11.440398	7.506427	10.678623
CI width	10.132474	0.610204	5.884923	1.768048
normalized CI width	0.899524318	0.0541717	0.522442135	0.156960893
hard variance	6.057	512.526		1262.166
normalized var.	0.062443299	5.283773196		13.01202062
hardness mean	6.1014285	68.6384615		46.7505
CI mean upper limit	8.377629	82.319093		63.377639
CI mean lower limit	3.825228	54.95783		30.123361
CI width	4.552401	27.361263		33.254278
normalized CI width	0.163578908	0.983157133		1.194907582
Nitrite variance				
normalized var.				
nitrite mean				
CI mean upper limit				
CI mean lower limit				
CI width				
normalized CI width				

Clear Fork continued

variance and confidence intervals	sh10	Cudjo	sr10	Network Statistics
nitrate variance	0.686	0.288		0.552
normalized var.	0.254074074	0.106666667		0.204444444
nitrate mean	0.65	1.3515385		1.022
CI mean upper limit	1.416098	1.675629		1.369807
CI mean lower limit	-0.116098	1.027448		0.674193
CI width	1.532196	0.648181		0.695614
normalized CI width	2.669628669	1.129361113		1.212006217
P variance	0.001	0.001		0.13
normalized var.	0.000588235	0.000588235		0.076470588
P mean	0.0864285	0.092692		0.1705
CI mean upper limit	0.119637	0.108614		0.33954
CI mean lower limit	0.05322	0.07677		0.00146
CI width	0.066417	0.031844		0.33808
normalized CI width	0.777789488	0.372915496		3.959153082
alk variance	11.954	594.326		1241.029
normalized var.	0.123237113	6.127072165		12.7941134
alkalinity mean	2.3228575	62.3153845		41.318
CI mean upper limit	5.520407	77.047352		57.805327
CI mean lower limit	-0.874692	47.583417		24.830673
CI width	6.395099	29.463935		32.974654
normalized CI width	0.502009498	2.312892299		2.588480571

Note: Sites in order upstream to downstream as go left to right

Tunnel Creek

variance and confidence intervals	tc10
DO % sat. variance	964.68
normalized variance	7.524804992
DO % sat. mean	85.159091
CI mean upper limit	98.93001
CI mean lower limit	71.388172
CI width	27.541838
normalized CI width	0.398833382
flow variance	0.145
normalized variance	0.185897436
flow mean	0.358
CI mean upper limit	0.963755
CI mean lower limit	-0.247755
CI width	1.21151
normalized CI width	7.816193548
ph variance	0.274
normalized variance	0.024909091
ph mean	7.953233
CI mean upper limit	8.043088
CI mean lower limit	7.863378
CI width	0.17971
normalized CI width	0.022546043
turbid variance	77.593
normalized variance	2.295650888
turbidity mean	8.99
CI mean upper limit	13.112581
CI mean lower limit	4.867419
CI width	8.245162
normalized CI width	1.412568443

TSS variance	3947.604
normalized variance	8.173093168
TSS mean	24.196205
CI mean upper limit	35.960516
CI mean lower limit	12.431894
CI width	23.528622
normalized CI width	4.033846866
temp variance	4.506
normalized variance	0.264747356
temperature mean	12.960909
CI mean upper limit	13.902045
CI mean lower limit	12.019773
CI width	1.882272
normalized CI width	0.147121463
hard variance	656.855
normalized variance	3.300778894
hardness mean	98.6706205
CI mean upper limit	103.5365
CI mean lower limit	93.804741
CI width	9.731759
normalized CI width	0.102637388
Nitrite variance	0.003
normalized variance	0.005172414
nitrite mean	0.029636
CI mean upper limit	0.03941
CI mean lower limit	0.019862
CI width	0.019548
normalized CI width	0.840557276

nitrate variance	0.819
normalized variance	0.096808511
nitrate mean	0.8858715
CI mean upper limit	1.057661
CI mean lower limit	0.714082
CI width	0.343579
normalized CI width	0.555234324
P variance	0
normalized variance	0
P mean	0.096892
CI mean upper limit	0.099457
CI mean lower limit	0.094327
CI width	0.00513
normalized CI width	0.05310559
alk variance	738.765
normalized variance	5.276892857
alkalinity mean	78.6419645
CI mean upper limit	83.731203
CI mean lower limit	73.552726
CI width	10.178477
normalized CI width	0.13970486

Station Creek

variance and confidence intervals	st10
DO % sat. variance	48.728
normalized variance	0.481026654
DO % sat. mean	94.7600045
CI mean upper limit	103.4275
CI mean lower limit	86.092509
CI width	17.334991
normalized CI width	0.183351748
flow variance	
normalized variance	
flow mean	
CI mean upper limit	
CI mean lower limit	
CI width	
normalized CI width	
ph variance	0.078
normalized variance	0.009285714
ph mean	7.563478
CI mean upper limit	7.683937
CI mean lower limit	7.443019
CI width	0.240918
normalized CI width	0.031871676
turbid variance	63.537
normalized variance	6.550206186
turbidity mean	10.95
CI mean upper limit	17.613939
CI mean lower limit	4.286061
CI width	13.327878
normalized CI width	3.443896124

TSS variance	5956.024
normalized variance	17.77917612
TSS mean	42.4444445
CI mean upper limit	80.822808
CI mean lower limit	4.066081
CI width	76.756727
normalized CI width	5.163934809
temp variance	16.185
normalized variance	0.909780776
temperature mean	14.15
CI mean upper limit	19.145248
CI mean lower limit	9.154752
CI width	9.990496
normalized CI width	0.736762242
hard variance	2157.176
normalized variance	11.98431111
hardness mean	58.333333
CI mean upper limit	81.430094
CI mean lower limit	35.236572
CI width	46.193522
normalized CI width	1.033944132
Nitrite variance	
normalized variance	
nitrite mean	
CI mean upper limit	
CI mean lower limit	
CI width	
normalized CI width	

nitrate variance	8.902
normalized variance	0.684769231
nitrate mean	1.4372225
CI mean upper limit	2.920934
CI mean lower limit	-0.046489
CI width	2.967423
normalized CI width	4.819592334
P variance	
normalized variance	
P mean	
CI mean upper limit	
CI mean lower limit	
CI width	
normalized CI width	
alk variance	2282.934
normalized variance	6.917981818
alkalinity mean	45.9411765
CI mean upper limit	70.507415
CI mean lower limit	21.374938
CI width	49.132477
normalized CI width	1.419451749

Lewis Hollow

variance and confidence intervals	lh5
DO variance	
normalized variance	
DO mean	
CI mean upper limit	
CI mean lower limit	
CI width	
normalized CI width	
flow variance	
normalized variance	
CI mean upper limit	
CI mean lower limit	
flow lower	
CI width	
normalized CI width	
ph variance	0.066
normalized variance	0.00825
ph mean	7.4142855
CI mean upper limit	7.562544
CI mean lower limit	7.266027
CI width	0.296517
normalized CI width	0.040015789
turbid variance	
normalized variance	
turbidity mean	
CI mean upper limit	
CI mean lower limit	
CI width	
normalized CI width	

TSS variance	7956.671
normalized variance	23.12985756
TSS mean	44.4535715
CI mean upper limit	95.956218
CI mean lower limit	-7.049075
CI width	103.005293
normalized CI width	6.277442165
temp variance	
normalized variance	
temperature mean	
CI mean upper limit	
CI mean lower limit	
CI width	
normalized CI width	
hard variance	148.989
normalized variance	2.811113208
hardness mean	29.7142855
CI mean upper limit	36.761881
CI mean lower limit	22.66669
CI width	14.095191
normalized CI width	0.511696471
Nitrite variance	
normalized variance	
nitrite mean	
CI mean upper limit	
CI mean lower limit	
CI width	
normalized CI width	

nitrate variance	0.027
normalized variance	0.054
nitrate mean	0.173571
CI mean upper limit	0.267919
CI mean lower limit	0.079223
CI width	0.188696
normalized CI width	1.640834783
P variance	
normalized variance	
P mean	
CI mean upper limit	
CI mean lower limit	
CI width	
normalized CI width	
alk variance	477.996
normalized variance	5.370741573
alkalinity mean	26.057143
CI mean upper limit	38.680539
CI mean lower limit	13.433747
CI width	25.246792
normalized CI width	1.228614142

Vita

Matthew Johnson was born in Knoxville, TN on July 24, 1979. He was raised in Morristown and Columbia, TN. He went to grade school at Riverside Elementary and Brown Elementary. He attended junior high at Whitthorne Middle School. He graduated from Columbia Central High School in 1997. After graduation, he went on to Tennessee Tech and received a B.S. in civil engineering in 2002.

Matthew is currently pursuing his M.S. in Environmental Engineering at the University of Tennessee, Knoxville.